

WL-TR-95-2111

DEVELOPMENT OF A BIPOLAR LEAD/ACID  
BATTERY FOR THE MORE ELECTRIC AIRCRAFT



JENNIFER L. ROSE

JOHNSON CONTROLS BATTERY GROUP, INC.  
5757 NORTH GREEN BAY AVENUE  
MILWAUKEE WI 53201-0591

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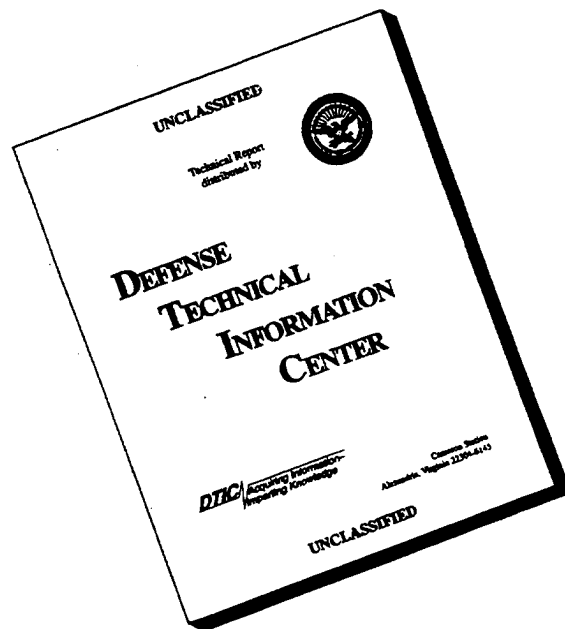
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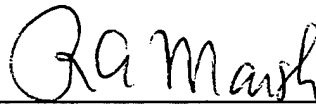
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R.A. MARSH  
Project Engineer



R.A. MARSH, Chief  
Battery Electrochemistry Section  
Power Technology Branch



MICHAEL D. BRAYDICH, Lt Col, USAF  
Chief, Aerospace Power Division

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## 1.0 SUMMARY

A 36-month contract was undertaken by Johnson Controls Battery Group, Inc. to develop a highly conductive, non-porous, and lightweight bipolar substrate and deliver a 56-volt prototype module for evaluation for the More Electric Aircraft. Eighteen months into Contract #F33615-91-C-2142, significant accomplishments were reported in the identification of suitable composite materials and in optimizing the compounding parameters of same. Laminated, 8 cm (L) x 8 cm (H) x 0.102 cm (TH) substrates with an overall resistivity of 4-6  $\Omega$ -cm were routinely manufactured in-house and used in battery builds. Over 150 cycles were demonstrated to 100% DOD at 0.16 A/cm<sup>2</sup> in a 4-volt battery configuration. Mass production oriented container molding was also demonstrated, however, process reliability was a major concern. Critical evaluation of the project in Month 33 recognized the difficulties in addressing recurrent substrate and paste adhesion delamination, as well as those to be solved in achieving high power (0.48+ A/cm<sup>2</sup>) capability from a 400+ cm<sup>2</sup> electrode. High power capability from a composite substrate was not deemed likely in the remaining contract period. Therefore, given its success in a parallel internally funded bipolar program, JCBGI requested a no-cost time extension to evaluate a new approach in metallic bipolar substrate technology. Five attempts were made at cladding strips of various corrosion resistant alloys, however, resultant materials were never suited to pasting or battery builds. Concurrent efforts to redesign the injection molded container succeeded in eliminating internal distortion of the metallic electrodes, but failed to resolve cell-to-cell leakage around the fill ports. At contract's end, deliverables utilizing a binary lead alloy and an alternative containment design were assembled, formed and delivered to WPAFB for test and evaluation.

Future composite bipolar substrate investigations based upon this body of work should focus on fostering positive paste adhesion. Continued metallic substrate work would benefit most from efforts to increase the substrate strength and corrosion resistance. Both designs require additional development of the injection molded containment concept to eliminate the catastrophic cell-to-cell leakage exhibited at the close of this contract.

## **2.0. WORK BREAKDOWN SCHEDULE**

As with other contract work performed at JCBGI, a Work Breakdown Schedule (WBS) was implemented to plan, execute, and monitor technical progress, costs, and scheduling. Tasks were identified as unitary efforts necessary to complete individual aspects of battery development, and subtasks further delineated each task. Composite plans, shown in Figure 1, were easily translated in August 1994 to more closely describe the efforts necessary to assemble a 24-volt bipolar battery utilizing metallic based substrates. These interpretations are shown in parentheses next to the composite substrate counterparts within Figure 1.



FIGURE 1: BMET WORK BREAKDOWN SCHEDULE

WBS 1.0 PROGRAM MANAGEMENT

- Subtask 1.1 Managing Strategy
- Subtask 1.2 Liaison/Meetings
- Subtask 1.3 Documentation
- Subtask 1.4 Contract Administration
- Subtask 1.5 Operating Supplies

WBS 2.0 BATTERY DESIGN

- Subtask 2.1 Battery System Design Analysis
- Subtask 2.2 Performance Modeling

WBS 3.0 BIPOLAR PLATE

- Subtask 3.1 Conductive Fillers (Multi-Alloy Substrate Development)
- Subtask 3.2 Substrate Fabrication Processes (Rolling/Embossing Work)
- Subtask 3.3 Stability Testing (Corrosion Testing)
- Subtask 3.4 Proof of Concept Testing (Small Scale Characterization)

WBS 4.0 BATTERY COMPONENTS

- Subtask 4.1 Separator Material
- Subtask 4.2 Active Material Development (Freeze/Thaw Work)

WBS 5.0 BATTERY FABRICATION

- Subtask 5.1 Sealing Methods (Lead to Plastic Interface Seal)
- Subtask 5.2 Formation

WBS 6.0 BMET DEMONSTRATION

- Subtask 6.1 Battery Fabrication (Deliverables)
- Subtask 6.2 Testing (Group 34 Cycling)

### 3.0 COMPOSITE SUBSTRATE DEVELOPMENT

#### 3.1 WBS 1.0 PROGRAM MANAGEMENT

##### 3.1.1 Subtask 1.1 Managing Strategy

Five review meetings were scheduled and attended by WPAFB and JCBGI personnel. These dates, as well as milestones achieved during the composite development phase of the contract, are shown in Gantt chart form in Figure 2.

#### 3.2 WBS 2.0 BATTERY DESIGN

##### 3.2.1 Subtask 2.1 Battery System Design Analysis

Preliminary performance requirements for the More Electric Aircraft (MEA) energy source were given to JCBGI by Richard Flake of WPAFB during the program kickoff meeting on December 12, 1991. The following energy sources were required:

Main Engine Starting:	150 kW, 30 sec
Ground Power:	25-75 kW, 30-45 min
Emergency Power:	75 kW, 10 min
APU Starting:	5-10 kW, 15 sec
Hybrid Emergency:	50-75 kW, 60 sec
Temperature Range:	-65°F to 120°F
Voltage Window:	270 volts (min), 330 volts (max)

Given this, JCBGI proceeded to use its proprietary lead/acid battery mathematical model to design near- and far-term bipolar systems having 5- and 10- year development time frames. Near-term modeling assumed that substrate program goals were reached and conventional active materials were used. The 10-year battery systems were projected assuming a thinner, more conductive substrate and improved active materials. The results, shown in Figures 3 through 14, dramatically illustrate the system configuration's dependence on application. Designs required as little as 0.18 ft<sup>3</sup> with a system mass of 33 pounds to as much as 8.13 ft<sup>3</sup> and 1349 pounds.

#### 3.3 WBS 3.0 BIPOLAR PLATE

##### 3.3.1 Subtask 3.1 Conductive Fillers

Initial work was focused on identifying an electronically conductive, filled polymeric composite having negligible ionic conduction which could short adjacent cells. The substrate was likewise required to be chemically inert to the electrode reactions, to have high oxygen and hydrogen overpotentials in H<sub>2</sub>SO<sub>4</sub>, and to be readily manufactured.

FIGURE 2: Composite Development Gantt Chart with Milestones

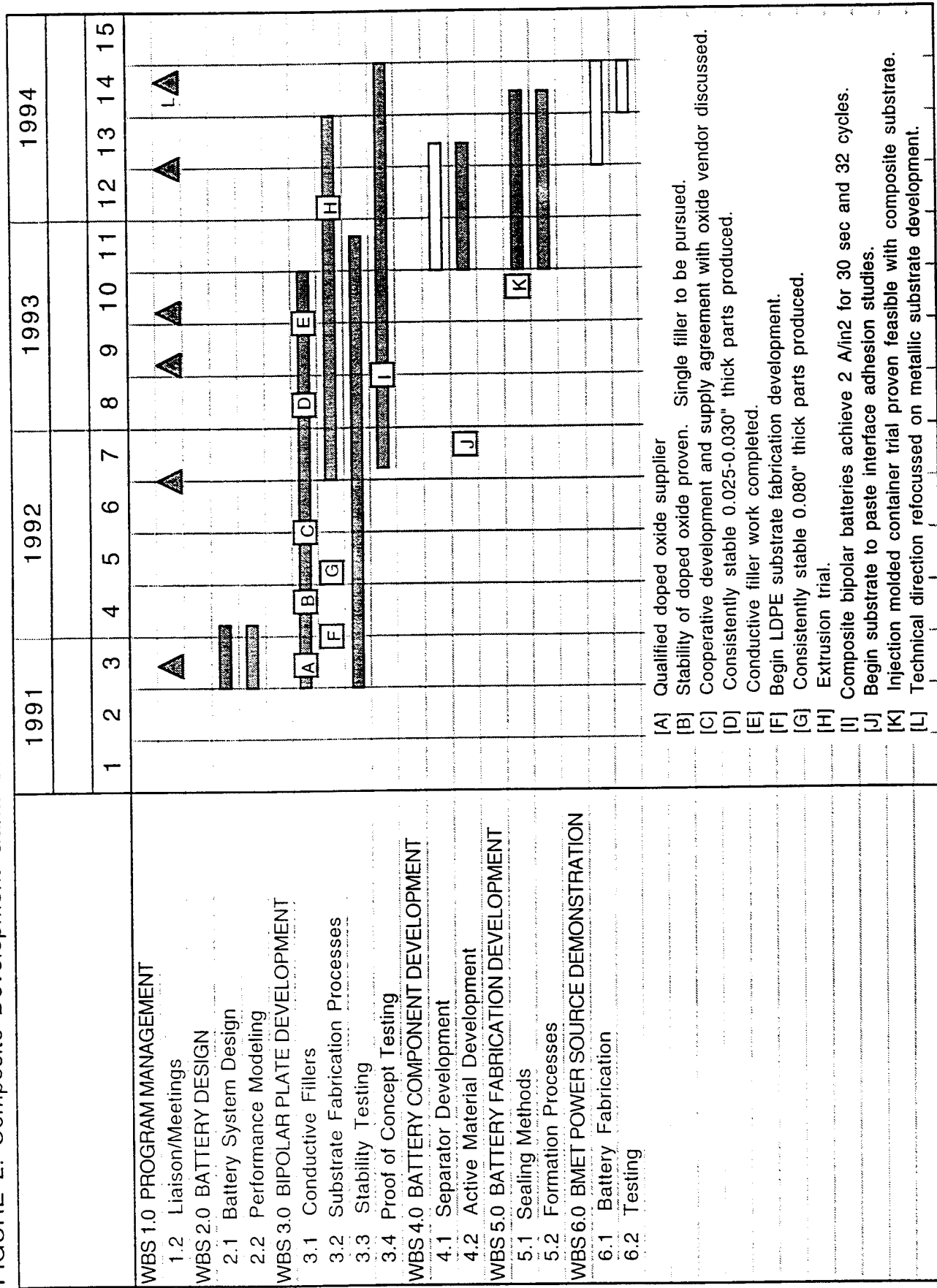


FIGURE 3

# NEAR AND FAR TERM BMET BIPOLAR BATTERY SPECIFICATIONS

<u>BATTERY TYPE</u>	<u>NEAR TERM</u>	<u>FAR TERM</u>
<b>Main Engine Starting</b>		
<b>Mass</b>	<b>450 lbs.</b>	<b>389 lbs.</b>
<b>Volume</b>	<b>2.45 ft<sup>3</sup></b>	<b>2.00 ft<sup>3</sup></b>
<b>Ground Power</b>		
<b>Lower Capacity Unit</b>		
<b>Mass</b>	<b>1000 lbs.</b>	<b>865 lbs.</b>
<b>Volume</b>	<b>6.15 ft<sup>3</sup></b>	<b>4.85 ft<sup>3</sup></b>
<b>Higher Capacity Unit</b>		
<b>Mass</b>	<b>1349 lbs.</b>	<b>1235 lbs</b>
<b>Volume</b>	<b>8.13 ft<sup>3</sup></b>	<b>6.72 ft<sup>3</sup></b>
<b>APU Starting</b>		
<b>Mass Volume</b>	<b>33.4 lbs.</b>	<b>30.6 lbs</b>
<b>Volume</b>	<b>0.18 ft<sup>3</sup></b>	<b>0.16 ft<sup>3</sup></b>
<b>Assumptions:</b>		
<b>Substrate Thickness</b>	<b>0.025"</b>	<b>0.010"</b>
<b>Substrate Weight</b>	<b>150 mg/cm<sup>2</sup></b>	<b>80 mg/cm<sup>2</sup></b>
<b>Substrate Resistivity</b>	<b>2.0 <math>\Omega</math>-cm</b>	<b><math>\sim</math>0 <math>\Omega</math>-cm</b>

FIGURE 4

**BMET PERFORMANCE REQUIREMENTS  
BIPOLAR BATTERY SPECIFICATIONS**  
Near Term Projections (within 5 years)  
330 Volt Battery Systems

REQUIREMENTS MET	BATTERY DIMENSIONS	BATTERY VOLUME	BATTERY WEIGHT	W/kg	W/cm <sup>3</sup>	W-hr/kg	W- hr/cm <sup>3</sup>
Main Engine Starting APV Starting Hybrid Emergency	17.6"x15.5"x15.5"	2.45 ft <sup>3</sup>	450 lbs	747.9	2.2	12.25	0.036
Main Engine Starting Ground Power Emergency Power APU Starting Hybrid Emergency							
Scenario 1 30 minute ground power capacity	27.4"x19.7"x19.7"	6.15 ft <sup>3</sup>	1000 lbs	62.2	0.16	31.08	0.081
Scenario 2 45 minute ground power capacity	36.2"x19.7"x19.7"	8.13 ft <sup>3</sup>	1349 lbs	46.1	0.12	34.56	0.092
APU Starting	16.5"x4.33"x4.33"	0.18 ft <sup>3</sup>	33 lbs	705.0	2.1	11.75	0.036

FIGURE 5  
 BMET PERFORMANCE REQUIREMENTS  
 BIPOLAR BATTERY SPECIFICATIONS  
 Far Term Projections (10 years)  
 330 Volt Battery Systems

REQUIREMENTS MET	BATTERY DIMENSIONS	BATTERY VOLUME	BATTERY WEIGHT	W/kg	W/cm3	W-hr/kg	W- hr/cm3
Main Engine Starting APV Starting Hybrid Emergency	14.4"x15.5"x15.5"	2.00 ft3	389 lbs	895.3	2.8	14.17	0.044
Main Engine Starting Ground Power Emergency Power APU Starting Hybrid Emergency							
Scenario 1 30 minute ground power capacity	21.6"x19.7"x19.7"	4.85 ft3	864 lbs	72.0	0.21	35.97	0.103
Scenario 2 45 minute ground power capacity	29.9"x19.7"x19.7"	6.72 ft3	1235 lbs	50.6	0.15	37.77	0.111
APU Starting	15.2"x4.33"x4.33"	0.16 ft3	31 lbs	772.0	2.3	12.87	0.041

FIGURE 6  
Comparison of Chemset and F2 Plates for  
Main Engine Starting Battery

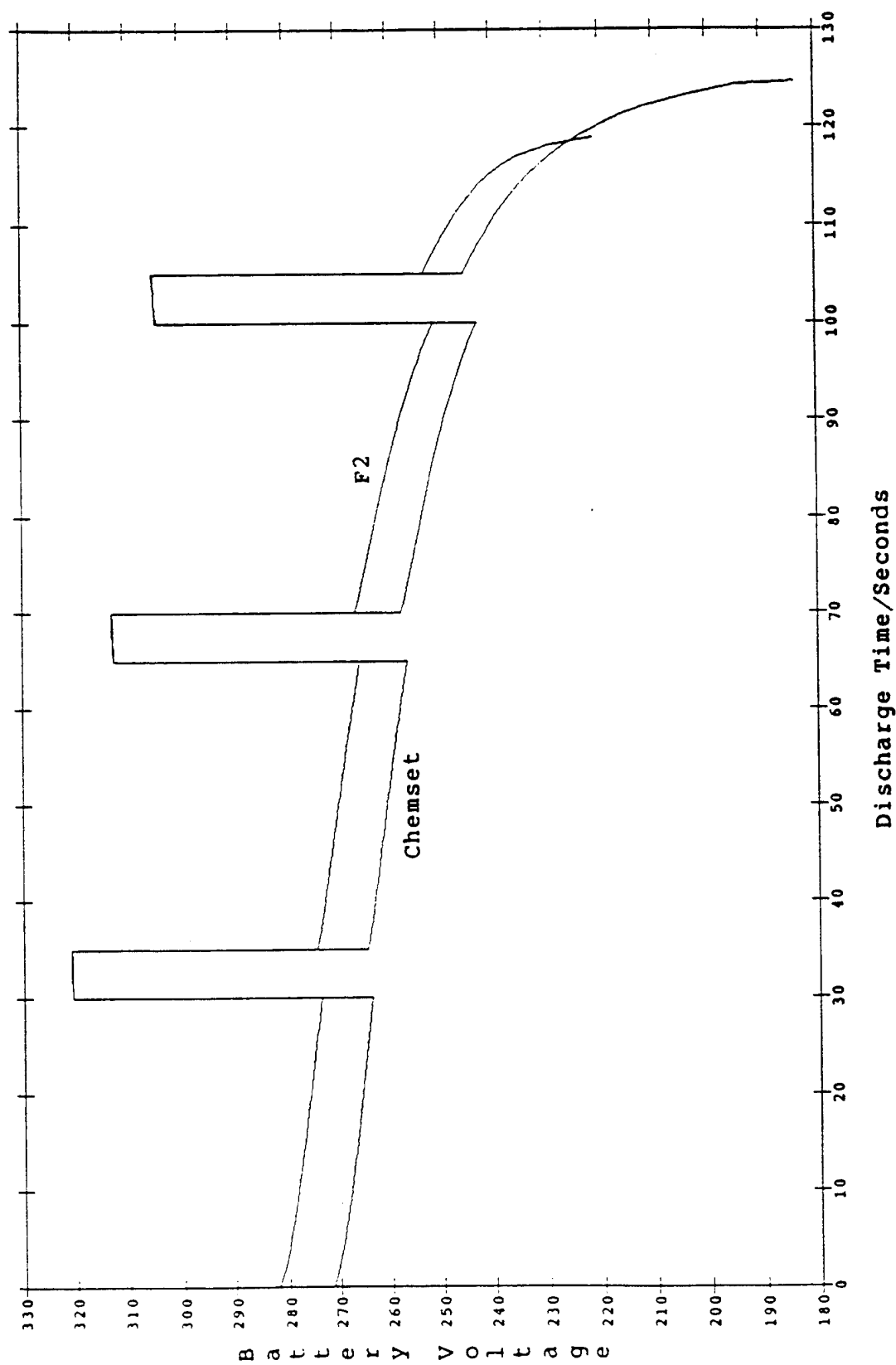


FIGURE 7  
Effect of Temperature on Performance  
of Main Engine Starting Battery

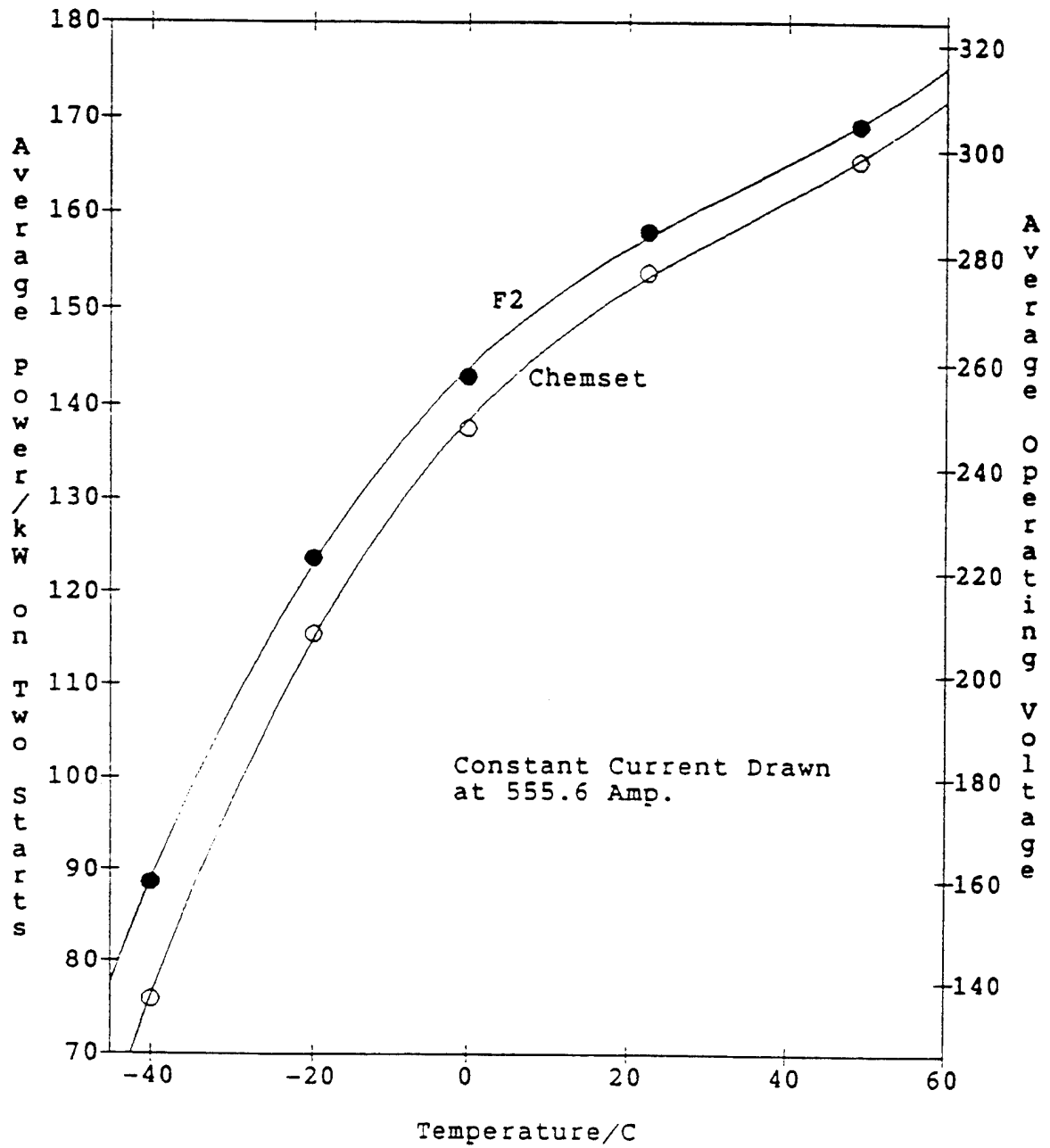




FIGURE 8  
Comparison of Chemset and F2 Plates for  
Ground Power Units

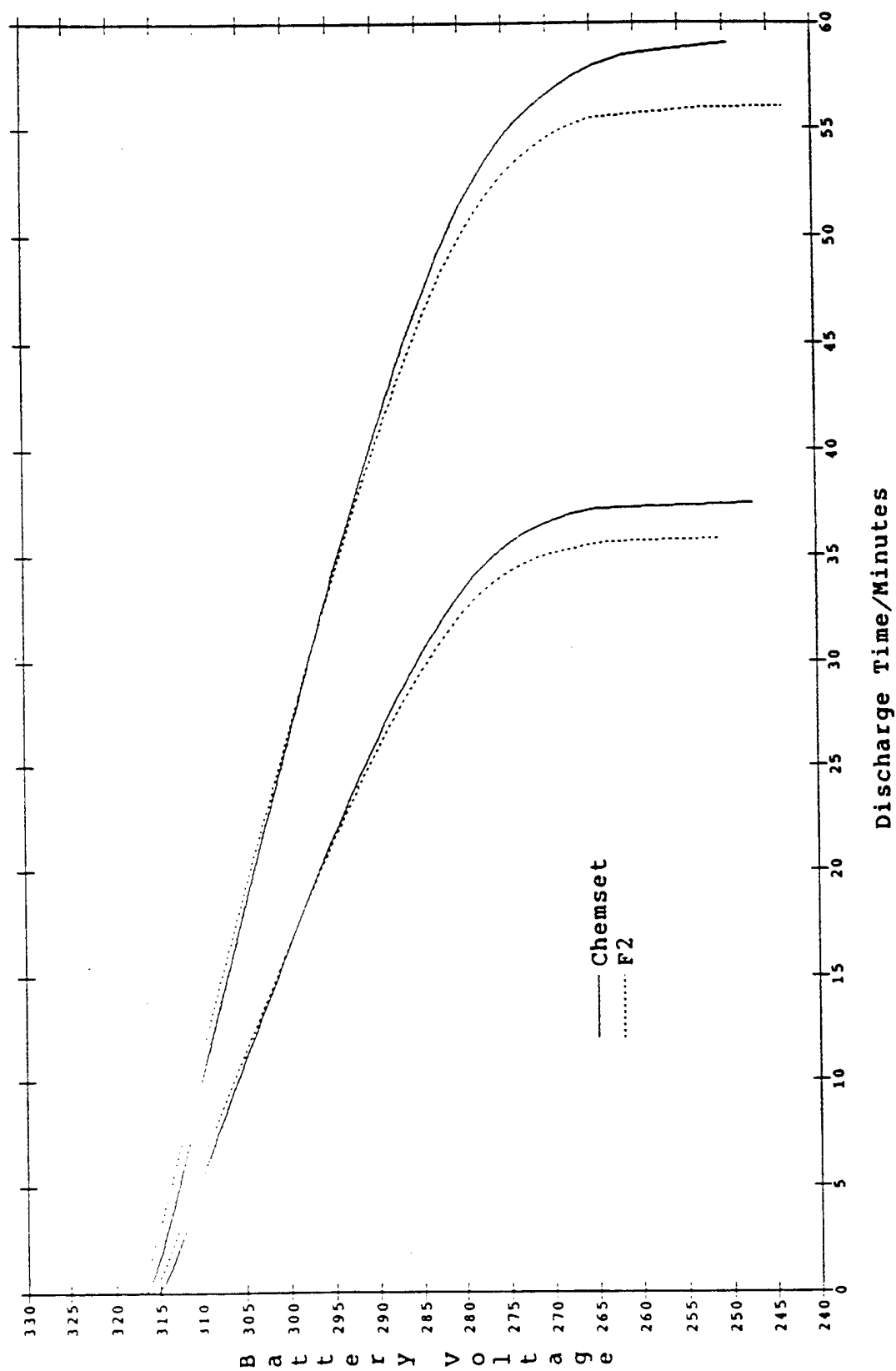


FIGURE 9  
Effect of Temperature on Power Output  
of the Ground Units

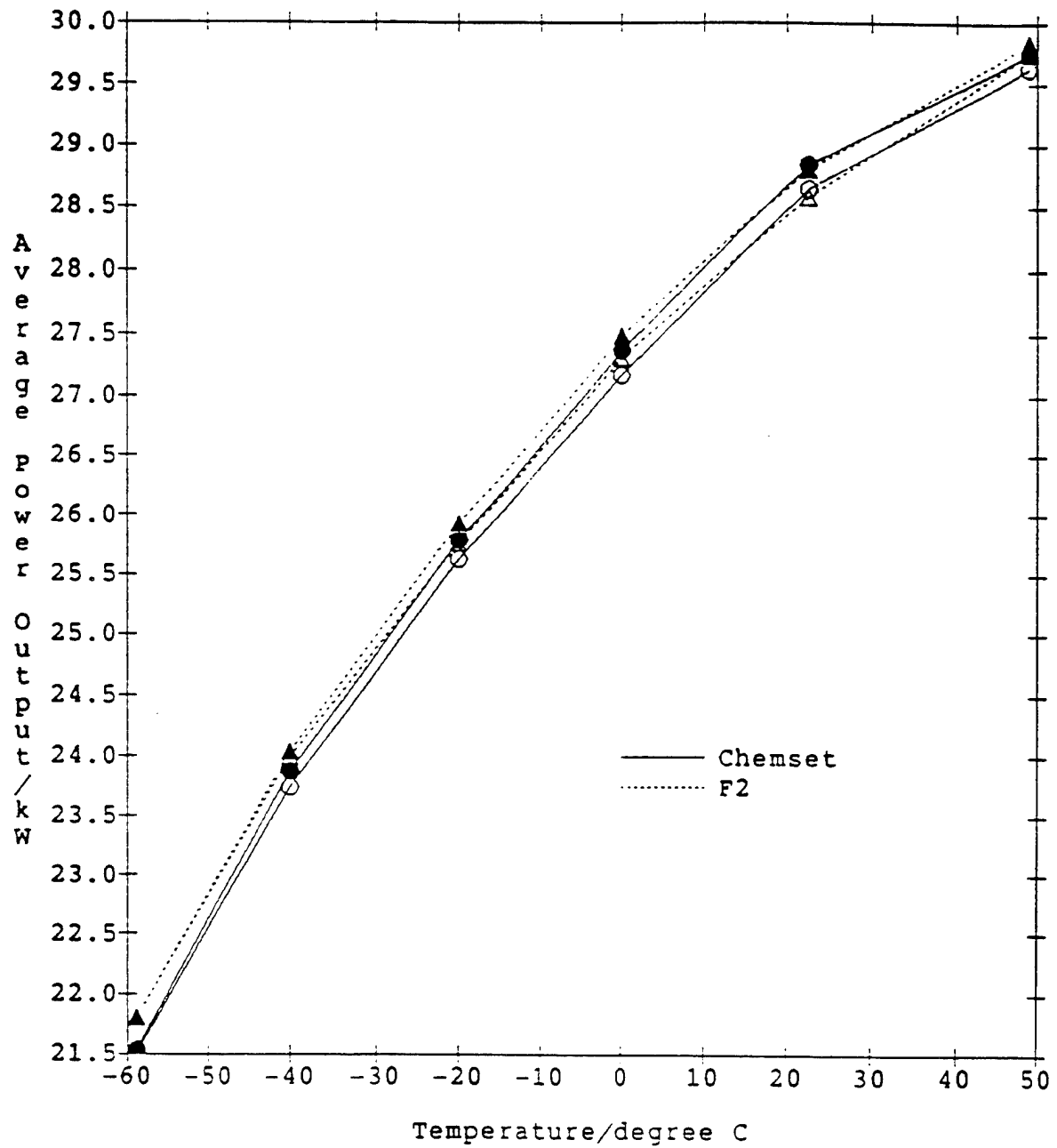


FIGURE 10  
Effect of Temperature on Capacity of  
the Ground Units

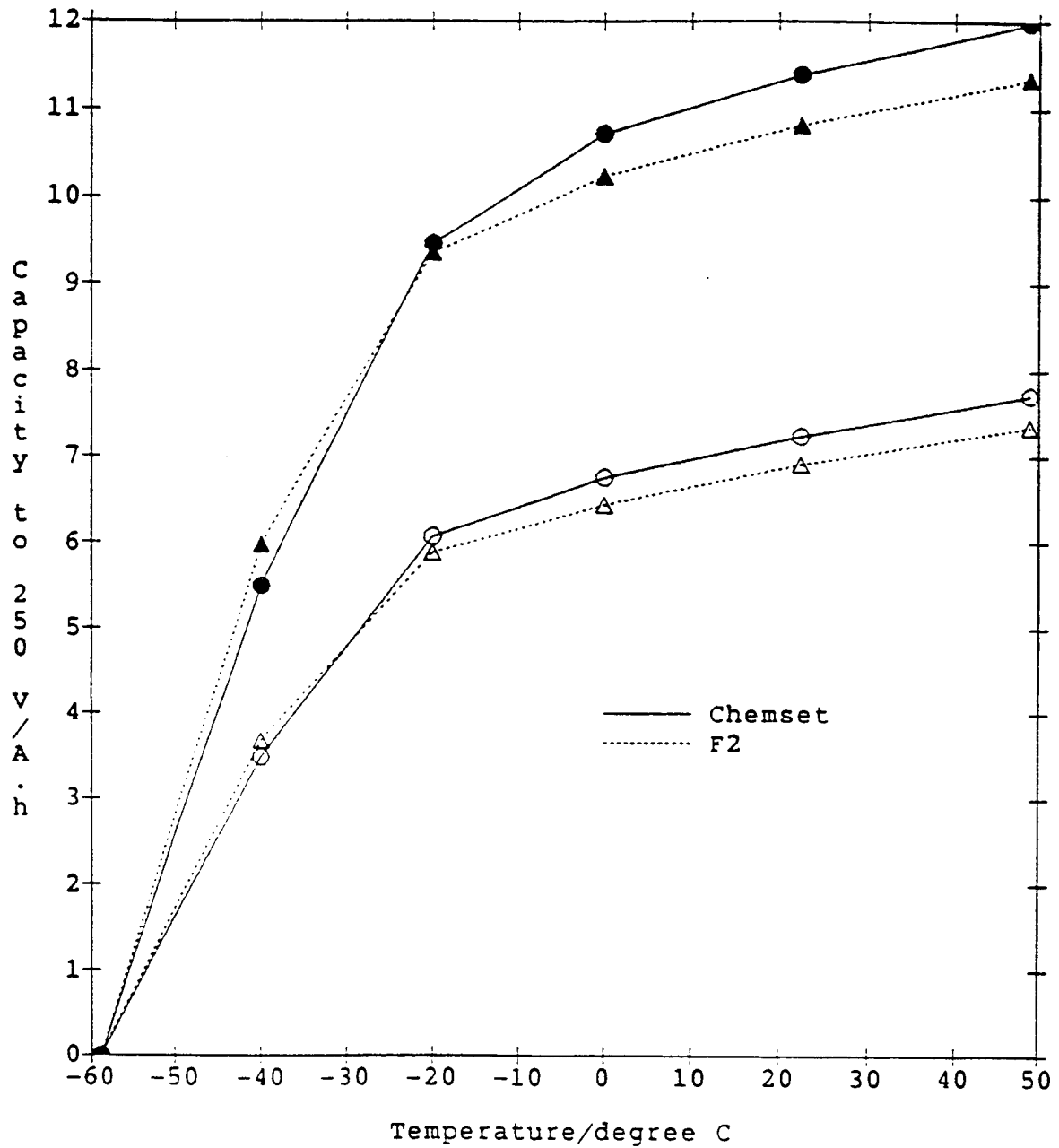


FIGURE 11  
Comparison of Chemset and F2 Plates for  
APU Starting Battery

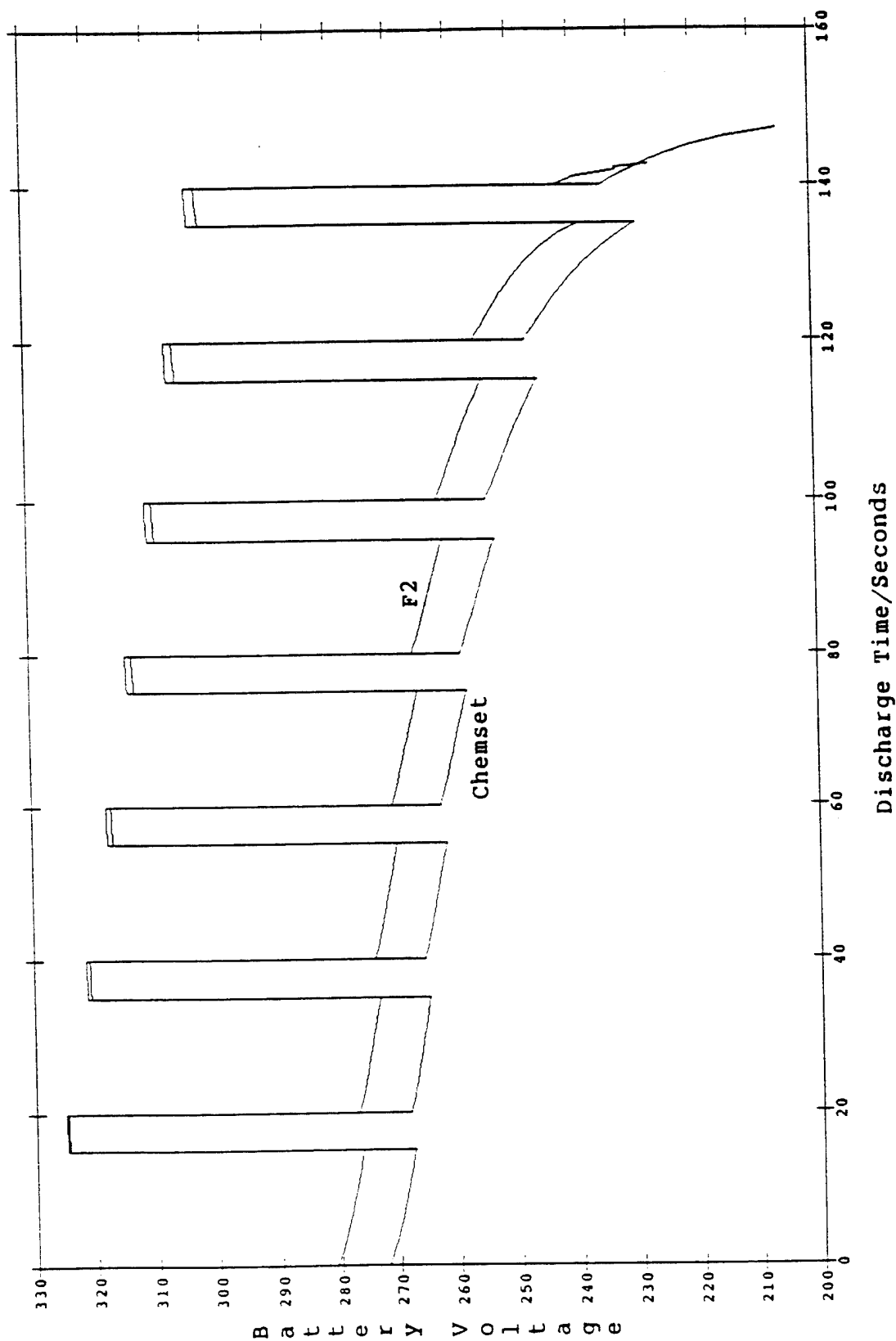


FIGURE 12  
Effect of Temperature on Performance  
of APU Starting Battery

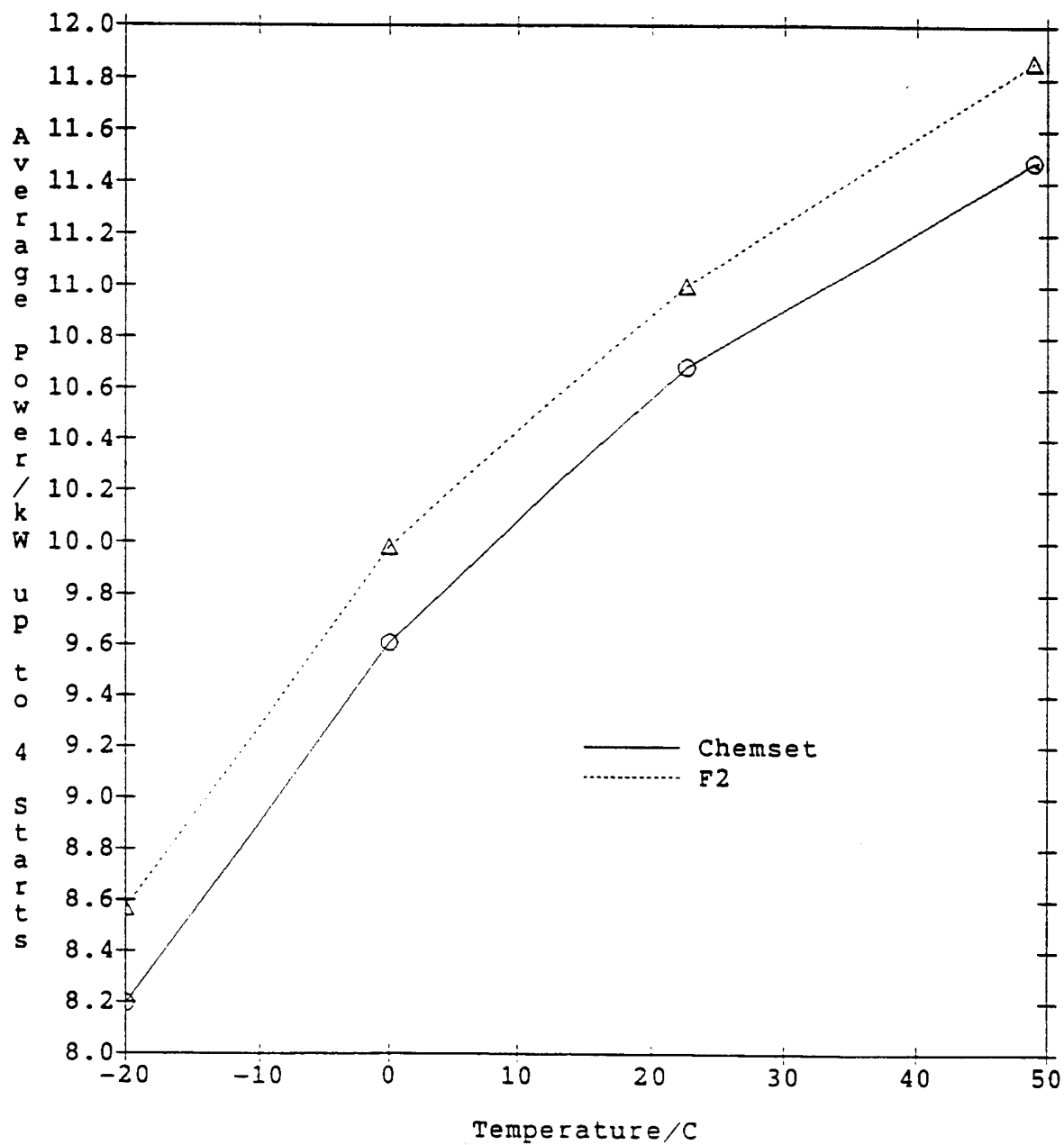


FIGURE 13  
Comparison of Chemset and F2 Plates for  
Emergency Power Unit

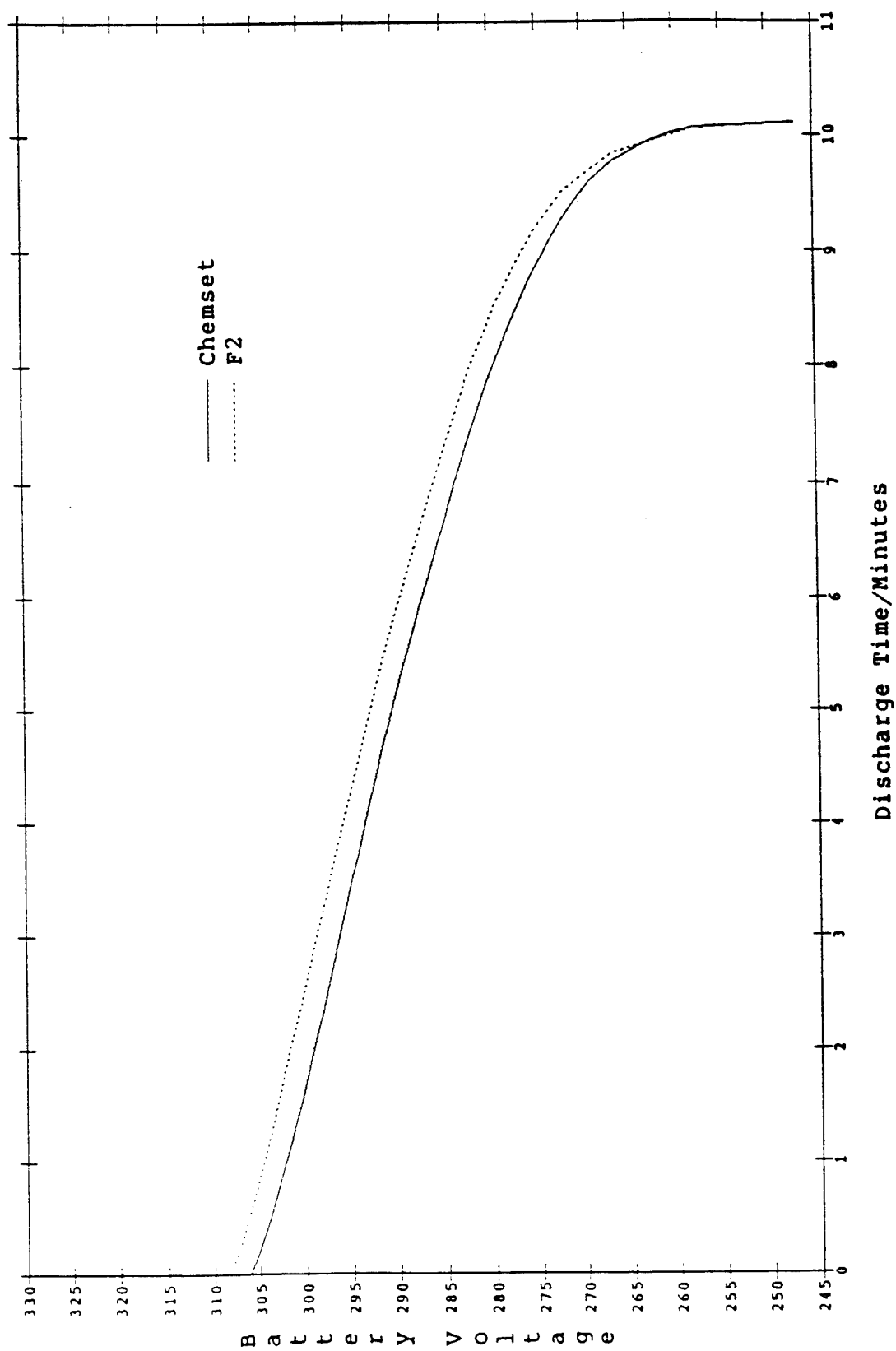
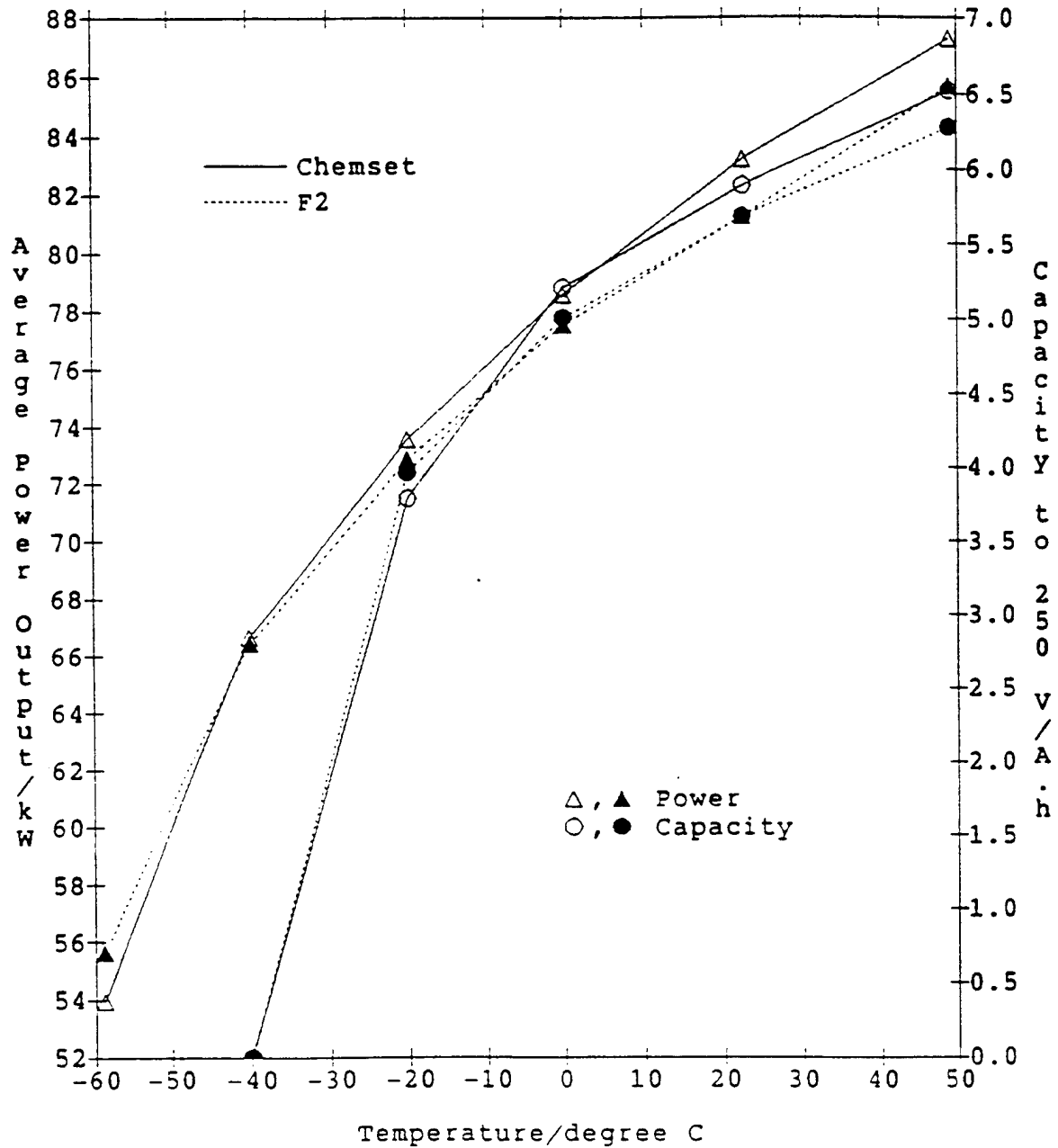


FIGURE 14  
Effect of Temperature on Performance  
of the Emergency Power Unit



Recognizing the recommendations from previous WPAFB work performed at JCBGI, conductive filler development resumed with further investigation of doped oxide. Coated glass fibers were also studied.

Initial work with Photon Energy Systems (PES) focused on coating doped oxide onto glass fibers. Four separate attempts were made with poor results. The first lot did not withstand the acid environment, and the second lacked uniformity and conductivity. Coated fibers from the third trial possessed no adhesion between the oxide and glass, hence were impossible to handle or compound into plastic. PES ultimately did coat 2-6" long fibers during a fourth trial, but was unable to supply the shorter lengths required for this application. Activity in this area was subsequently discontinued.

Efforts by Materials and Electrochemical Research, Inc. (MER) to produce a dense plaque of doped oxide met with similar difficulties. Prototype samples lost all conductivity and dissolved when put in contact with  $H_2SO_4$ . A carbide compound was also provided, but found too resistive. No further attempts were made.

Two companies were next contacted for samples of doped oxide in powder form. Provided materials were extremely similar in particle size and appearance, and remained stable throughout acid leach testing. Replicate samples of 85% and 90% loaded plastic were then prepared. Measurements showed the oxide from Magnesium Elektron, Inc. (MEI) to be seven to fifteen times more conductive than that obtained from Crystal Research, Inc. (CRI). Throughout ensuing months, MEI recognized the product potential, entered into a joint development (JD) effort with JCBGI, and supplied over \$110,000 worth of oxide to JCBGI at no cost. Leftover material was returned per the appropriate clause in the JD. Additional oxides doped with other elements were prepared by MEI late in the contract, but shown highly resistive and unstable during JCBGI testing. MEI was also instrumental in providing compounding expertise that greatly expedited the development effort.

Particle size optimization was one such area in which MEI provided invaluable help. JCBGI initially believed that a smaller particle size (1 micron) would reduce porosity due to its being more easily wetted by the surrounding plastic resin. Trials using fines screened from the supplied material proved the contrary with regard to both conductivity and porosity. Resistivity readings increased twenty-fold. Discussions with MEI's compounding experts revealed that the use of uniformly shaped, ultrafine particles made it more difficult to achieve the needed particle-to-particle chain of contact through the thickness of the material, i.e. increased resistance. The smaller particle size also increased the available surface area at which pores could and did develop. All contract work was performed using particles roughly 3-5 microns in diameter. Use



of the estimated 10-20 micron optimum particle would have required an entirely different production method. Time and associated costs of the changeover were far beyond the scope of this program.

Subsequent electrical testing of the MEI material showed the doped oxide to lack stability at negative electrode potentials. This finding required doped oxide be used as a laminate in conjunction with a material better able to withstand the environment at the negative plate. Carbon black was immediately proposed as the ideal partner, having been previously identified as highly conductive, lightweight, readily available and stable at negative potentials during the first WPAFB contract. Compounding trials optimized the loading, resulting in highly conductive parts that were also very flexible.

Compounding descriptions and the corresponding conductivity measurements are provided as figures in the text.

### 3.3.2 Subtask 3.2 Substrate Fabrication Techniques

Given the limited batch size and trial-to-trial variability in hand compounding plastic and filler, resins were carefully chosen for study. These included low-density polyethylene (LDPE), fluoropolymer formulations (Kynar), polytetrafluoroethylene (PTFE), and high-density polyethylene (HDPE).

Given its use in prior WPAFB-sponsored work, initial efforts focused on LDPE and Microthene™ from Quantum Chemical Corporation was purchased. A powdered form was requested and received to facilitate uniform filler dispersion with minimum porosity. Dry mixing of the filler and resin was accomplished by hand using a mortar-and-pestle early on in the contract. This was later replaced by V-blending. The mixture was then melt blended in a twin screw extruder to produce pellets that were compression molded into sheet form. Early samples were thick (0.070") and used exclusively for proving the stability of the filler. After several successful resistivity tests, work was redirected on thinning the part and making it more conductive.

Another resin, PTFE, was investigated concurrently. Loadings from 70-75% produced highly conductive parts, however, these were also very porous. Investigations were undertaken with Imprex, Inc. to impregnate the porous parts under vacuum with a polycarbonate-based liquid resin to reduce the porosity without hindering the conductivity. PTFE development was stopped when samples were shown to have remained porous and become even more resistive following treatment.

Kynar was also explored for use as a base resin. The material showed initial promise, during producing conductive and nonporous material during hand compounding trials. However, the 375°C temperature needed to soften and melt the resin degraded the doped oxide. LDPE and Kynar blends resulted in conductive but highly porous material. Development in this area was discontinued given the successes with LDPE.

Additives were next employed to improve the physical properties of the substrate. Coupling agents, oils, acids, acetates and silicon compounds were each investigated in an attempt to improve part conductivity, reduce porosity, and/or improve manufacturing. Coupling agents, designed to bond the filler and surrounding base resin, offered the only quantifiable advantage. Of particular note was a coupling agent available through Kenrich Chemical, Incorporated. Additions substantially improved the resultant substrate's physical properties. Order of addition was also found critical to the end product. Greatest effectiveness was had in dry mixing with doped oxide prior to adding LDPE powdered resin.

Lastly, JCBGI investigated HDPE resin in an effort to widen the operating temperature range of the battery. Initial stability tests showed high porosity levels. Increasing the melt blend temperature produced stable parts. Development was halted in June 1994 when the program's technical direction was changed (see Section 4.0 - Metallic Substrate Development).

Alternative methods of producing sheet stock were also investigated. Molded Rubber and Plastics (MRP) and JCBGI teamed to design a vacuum compression mold to remove trapped gases and produce pore free parts. Unfortunately, samples exhibited physical properties no better than parts made in the conventional manner. Work was discontinued due to the prohibitive \$75/part cost and the large volume of material needed per trial (10+ pounds).

Skiving was no more successful. Thin rolls of doped oxide in Microthene™ were received from DeWal Industries in May 1993 for laminating and resistivity testing. Resultant laminates were 0.029-0.031" thick with resistivities in the range of 1.7-2.0 Ω-cm. Given the promise of the materials produced by DeWal's skiving process, JCBGI twice supplied additional compounded materials for processing into sheet. Doped oxide samples exhibited low initial porosities that increased as a result of the laminating process; the porosity of the carbon black material was never acceptable. Work with DeWal was subsequently discontinued.

Carbon-black development proceeded more quickly with the aid of JCBGI's zinc-bromine battery development program. Several different types of carbon-black were screened and a Ketjenblack material from Azko Chemical was chosen. Compounding trials identified an optimum carbon-black loading level that afforded parts with a conductivity of 1-1.6 ½-cm and enough flexibility to be used as a bipolar substrate.

Laminating the filled LDPE substrates was next addressed. Early laminates exhibited a resistivity higher than the sum of the constituent pieces due to the "skin" formed on the surface of each sheet when molded. Two methods of removing the "skin" were tried. The addition of carbon black at the interface prior to laminating proved effective, but difficult to perform in a uniform manner. The second and adopted method required gentle sanding of the skinned surfaces with sandpaper. Sanding prior to lamination resulted in a 50-75% reduction in part resistivity and no effect on part stability.

### 3.3.3 Subtask 3.3 Stability Testing

The procedure and fixture for quantifying a bipolar substrate's stability in acid and under potential were developed at JCBGI over many years. Both three- and four-point tests were required to evaluate a sample's viability.

As shown in Figure 15, a substrate sample was clamped between two hollowed polycarbonate endblocks, exposed to electrolyte, and wired as the working electrode. A potential of 1.5 volts was applied and the current collected at the top of the substrate in the three-point system. After 24 hours on test to establish a baseline current, the leads were rearranged to collect current after passing through the substrate, i.e., the four-point test. The test continued for a minimum of 3 additional days. No change in the current acceptance established the sample to be nonporous. A rising current suggested porosity or filler instability. Detailed stability results are provided in Appendix B.

Conductivity before and after the three- and four-point regimen was also monitored. An increase of 20% or more signalled porosity or filler instability. Since doped oxide had been successfully tested, an increase in resistivity was interpreted as increasing porosity, i.e., carbon-black was exposed to the positive potential as a result of the porosity causing the carbon-black to oxidize and become nonconductive.

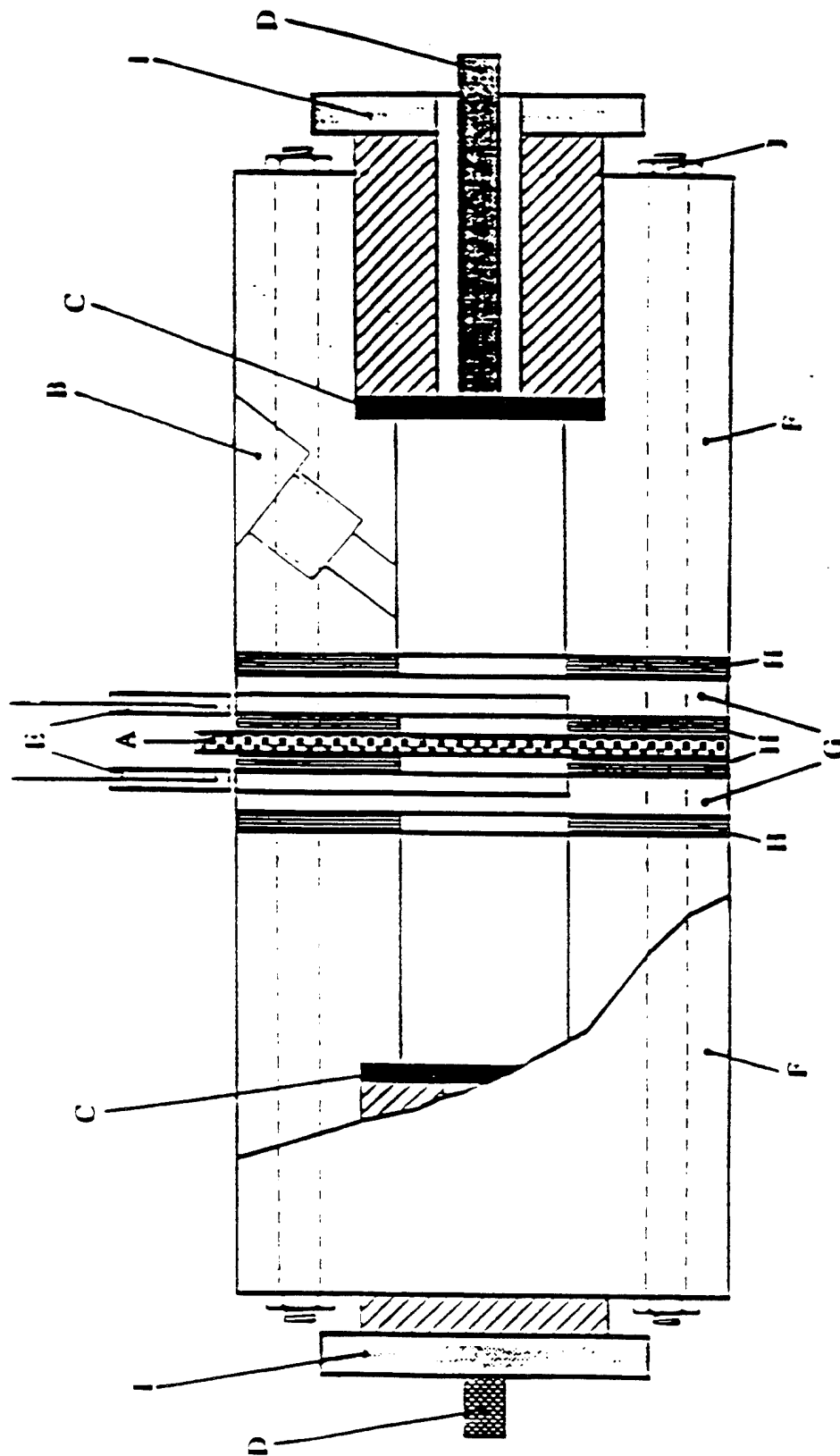
### 3.3.4 Subtask 3.4 Proof of Concept Testing

Over 60 batteries of various voltages were assembled and tested. Dry, unformed electrodes with 10 in<sup>2</sup> active areas were alternately stacked with elastomeric spacers and compressed to dimension between 0.5" thick polycarbonate end plates. Insulated bolts positioned around the perimeter of the fixture were easily tightened to compress the gaskets to affect hermetic cell seals. Absorptive glass mat separator was placed between opposing electrodes and filled with electrolyte through channels machined across the upper portion of each

# FIGURE 15

## Stability Test Fixture

- |                               |                              |
|-------------------------------|------------------------------|
| A. Bipolar Substrate          | F. Lexan Block               |
| B. Reference Electrode Socket | G. Spacer with Sensor Socket |
| C. Counter Electrode          | H. Gasket                    |
| D. Current Collector          | I. Counter Electrode Bushing |
| E. Resistance Sensor          | J. Clamping Hardware         |



gasket. Discharge performance routinely surpassed 5 minutes at 1 A/in<sup>2</sup>, but with limited cycle life.

Laminate and positive paste adhesion were the ultimate issues and numerous approaches were investigated in attempts to foster them. Techniques included roughening the pasted surface with various grit sandpaper, embedding fibers, sintering lead dust or oxide powder onto the active areas, flame spraying lead, pretreating the plastic to increase its wettability. A review of the battery build sequence, documented in Figure 16, quickly shows that any battery formed without the use of lead sheet could not be tested due to high internal resistances caused by poor paste adhesion.

The major breakthrough occurred upon recognizing the special needs of polyolefins. Involved surface pretreatments are recognized as necessary to achieve bonds with wax-like surfaces that are difficult to wet if left alone. Surface treating LDPE prior to attaching a layer of thin lead foil decreased the part resistivity by 50-75%. Over 150 cycles were demonstrated with shorting as the cause of failure. Subsequent builds neared this benchmark, however, lead foil delamination became a recurring problem. Substrate conductivities checked prior to pasting and after cycling showing no change added to the confusion. Treatment parameters were reviewed and found incorrect, resulting in delamination *within* the plastic part. Optimization trials were initiated, along with investigations of HDPE resin. HDPE was proven to bond more strongly to lead sheet, but the resulting cycle life was still unacceptable. Efforts were halted with the change in the program's technical direction.

### 3.4 WBS 5.0 BATTERY FABRICATION

#### 3.4.1 Subtask 5.1 Sealing Methods

Two 10-volt batteries were produced using an injection molded containment method in October 1993. Electrodes, separators and spacer frames were arranged to form a stack that was inserted into a cavity for molding. Plastic injected into the mold formed a frame around the entire stack to provide the necessary sealing and spacing requirements, as well as provisions for acid fill.

Electrode quality within each 10-volt stack was poor due to the required part size. Length and width exceeded the working area of the press. Pieces were 0.080" thick and highly resistive (10  $\Omega$ -cm). Cross sectioning of one dry, unformed (DUF) stack showed complete plastic fill and no electrode distortion. Confirmation of hermetic cell-to-cell sealing was never

FIGURE 16  
Composite Battery Builds

ID	Volts	Adhesion Method	Cycles	Cause of Failure
159	4	Lead dust	32	Lack of paste adhesion
159-B	4	Lead dust	15	Lack of paste adhesion
160	4	Lead dust	15	Lack of paste adhesion
182-1	4	Lead dust	5	PbSO <sub>4</sub> at surface
182-2	4	Sanded surface	5	Lack of paste adhesion
182-3	4	Lead dust	5	PbSO <sub>4</sub> at surface
182-4	4	Sanded surface	5	Lack of paste adhesion
194-3A	4	Embedded 0.003" glass mat	0	PbSO <sub>4</sub> at surface
194-4A	4	Embedded 0.003" glass mat	0	PbSO <sub>4</sub> at surface
194-3A	4	Finely sanded surface	0	PbSO <sub>4</sub> at surface
194-4A	4	Finely sanded surface	0	PbSO <sub>4</sub> at surface
205-1	4	0.001" perforated lead foil	18	Lack of paste adhesion
205-2	4	0.001" perforated lead foil	18	Lack of paste adhesion
205-3	4	0.001" lead foil	19	Lack of paste adhesion
205-4	4	0.001" lead foil	14	Lack of paste adhesion
214-1	4	0.010" lead foil over treated surface	18	Leak, cracked substrate
214-4	4	0.010" lead foil	21	Lead foil delamination
214-5	4	0.010" lead foil	45	One very dry cell
214-6V	6	0.010" lead foil over treated surface	47	Lead foil delamination
218-1	4	Carbide fibers	2	Too resistive to cycle
218-2	4	Carbide fibers	2	Too resistive to cycle
224-4	4	0.010" lead foil over treated surface	151	Shed PAM, shorting
224-5	4	0.010" lead foil over treated surface	104	Lead foil delamination
241-2	4	Flame sprayed lead	0	High IR, no AM adhesion
242	12	0.005" lead foil over treated surface	15	Lead foil delamination
242-4	4	Paste over treated surface	0	High IR, no AM adhesion
243-6V	6	0.005" lead foil over treated surface	12	Lead foil delamination
257	12	0.005" lead foil over treated surface	8	Lead foil delamination
259	12	0.005" lead foil over treated surface	0	Lead foil delamination
260-2	4	0.005" lead foil over treated surface	19	Lead foil delamination
263	6	0.005" lead foil over treated surface	9	Lead foil delamination
265	6	0.005" lead foil over treated surface	4	Crack, leak, delamination
267-1C	4	0.005" lead foil over treated surface	15	Lead foil delamination
267-4P	4	0.005" lead foil over treated surface	135	Local lead foil delamination
267-5P	4	0.005" lead foil over treated surface	13	Local lead foil delamination
267-6VP	6	0.005" lead foil over treated surface	33	Local lead foil delamination
267-6P	4	0.005" lead foil over treated surface	18	Local lead foil delamination
267-8C	4	0.005" lead foil over treated surface	20	Local lead foil delamination
267-9P	4	0.005" lead foil over treated surface	20	Local lead foil delamination
267-11C	6	0.005" lead foil over treated surface	11	Local lead foil delamination
268-6VC	6	0.005" lead foil over treated surface	11	Local lead foil delamination
268-8C	4	0.005" lead foil over treated surface	9	Local lead foil delamination
268-10C	4	0.005" lead foil over treated surface	68	Local lead foil delamination
268-11C	4	0.005" lead foil over treated surface	135	Local lead foil delamination
268-12C	12	0.005" lead foil over treated surface	15	Lead foil delamination
277-1C	4	0.005" lead, treated surface, acid dip	2	Local lead foil delamination
277-2C	4	0.005" lead, treated surface, acid dip	4	Local lead foil delamination
277-6VC	6	0.005" lead, treated surface, acid dip	3	Local lead foil delamination
278-1C	4	0.005" lead, treated surface, acid dip	8	Local lead foil delamination
281-1	4	0.005" lead on HDPE, treated surface	6	Local lead foil delamination
282-1	4	0.005" lead on HDPE, sanded, treated surface	23	Lead foil delamination
282-2	4	0.005" lead on HDPE, sanded, treated surface	5	Lead foil delamination
282-6V	6	0.005" lead on HDPE, sanded, treated surface	5	Lead foil delamination
285-1	4	0.005" lead, washed oxide, treated surface	11	Lead foil delamination
286-2	4	0.005" lead, unwashed oxide	0	Short
286-3	4	0.005" lead, unwashed oxide	11	Lead foil delamination
287-2	4	0.005" lead on HDPE, washed, treated surface	1	Cracked substrate
287-3	4	0.005" lead on HDPE, treated surface	10	Lead foil delamination
287-4	4	0.005" lead on HDPE, treated surface	6	Cracked substrate

obtained due to difficulties porting the cells for pressurization tests. The trial did, however, prove that injection molded containment was a viable manufacturing technique.

## **4.0. METALLIC SUBSTRATE DEVELOPMENT**

### **4.1 WBS 1.0 PROGRAM MANAGEMENT**

#### **4.1.1 Subtask 1.1 Managing Strategy**

Effective July 28, 1994, Ms. Jennifer Rose assumed the responsibilities of the contract's previous project engineer, Mr. Doug Pierce, due to his departure from JCBGI.

Shortly thereafter, a proposal requesting a no-cost time extension was submitted to the contract negotiator on July 13, 1994. Gantt charts detailing this effort are shown in Figures 17 and 18. This followed a discussion with Mr. Richard Marsh during which it was mutually agreed that, despite significant advances in composite bipolar substrate development, remaining WPAFB contract work should be focussed on the use of a lead substrate with improved corrosion resistance. Through a parallel bipolar program, JCBGI had repeatedly demonstrated 2000+ cycles in a 12-volt configuration utilizing lead substrates, and over 5700 cycles using a 6-volt unit. Laminated metallic substrate work had also been underway for nearly 12 months in an effort to increase corrosion resistance, and hence, cycle life.

### **4.2 WBS 2.0 BATTERY DESIGN**

#### **4.2.1 Subtask 2.1 Battery System Design Analysis**

The existing small metallic bipolar battery design was scaled up and modeled to investigate high power performance. Results suggested the use of a thinner cell design to be critical to achieving rates of 500 W/kg and higher. Per these findings, work was redirected to designing a 24-volt module within the volume previously allotted for 12-volts. This effectively aligned the contract deliverable voltage with WPAFB's ultimate application and JCBGI's commercial product target. Constant power performance projections are shown in Figure 19.

### **4.3 WBS 3.0 BIPOLAR PLATE**

#### **4.3.1 Subtask 3.1 Multialloy Substrate Development**

Under separate contract, JCBGI began investigations into laminated metal substrates in November 1993. Corrosion testing of three, four and five layer samples and constituent alloys was performed in a bipolar configuration to assess time to breakthrough. Unpasted samples were mounted in the previously described stability test fixtures (Composite Substrate Work, Subtask 3.3) for three-point testing. Only the positive surface was exposed to electrolyte. Working and reference electrodes were also introduced. Initial testing of a new material was





FIGURE 18: WPAFB Bipolar Deliverable Schedule

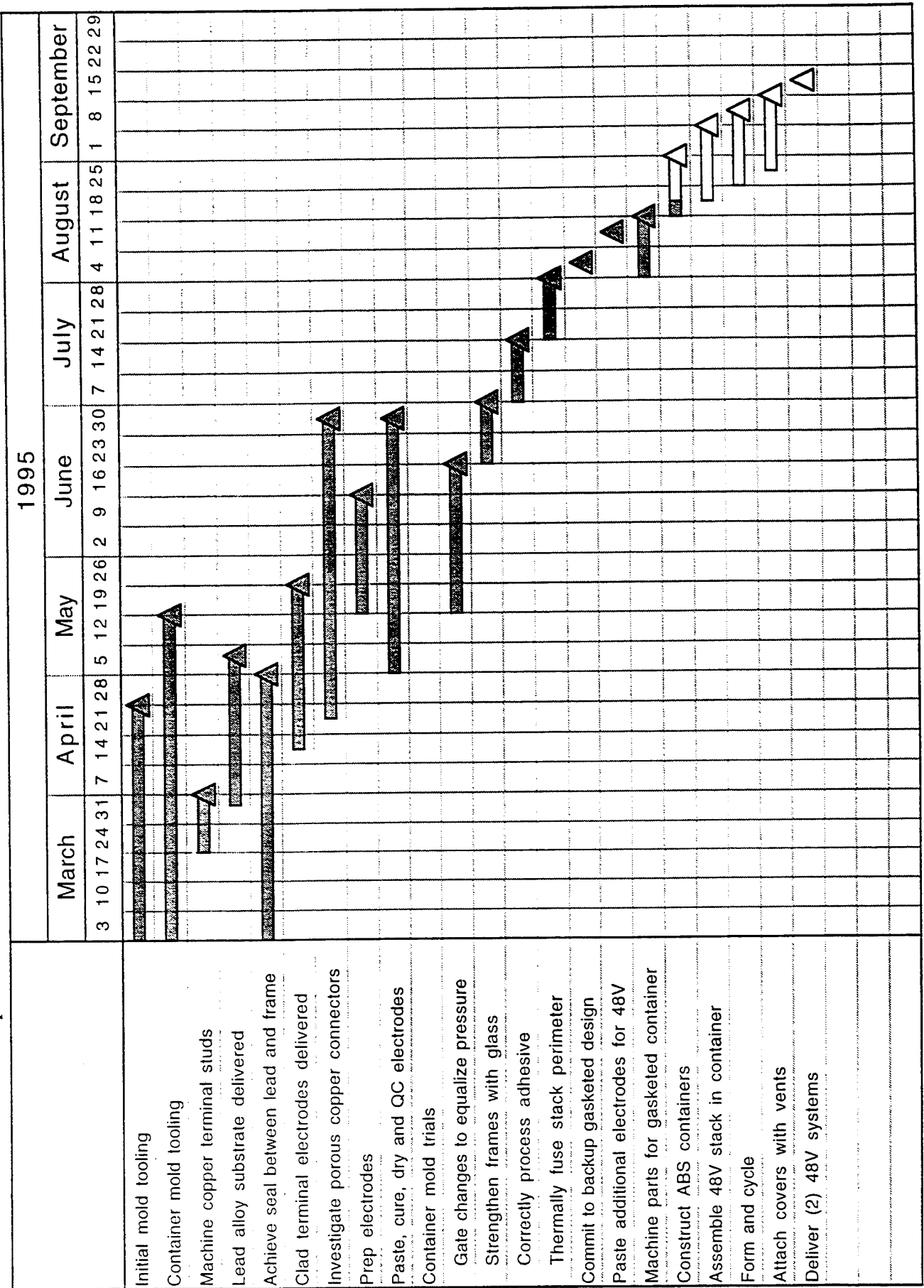
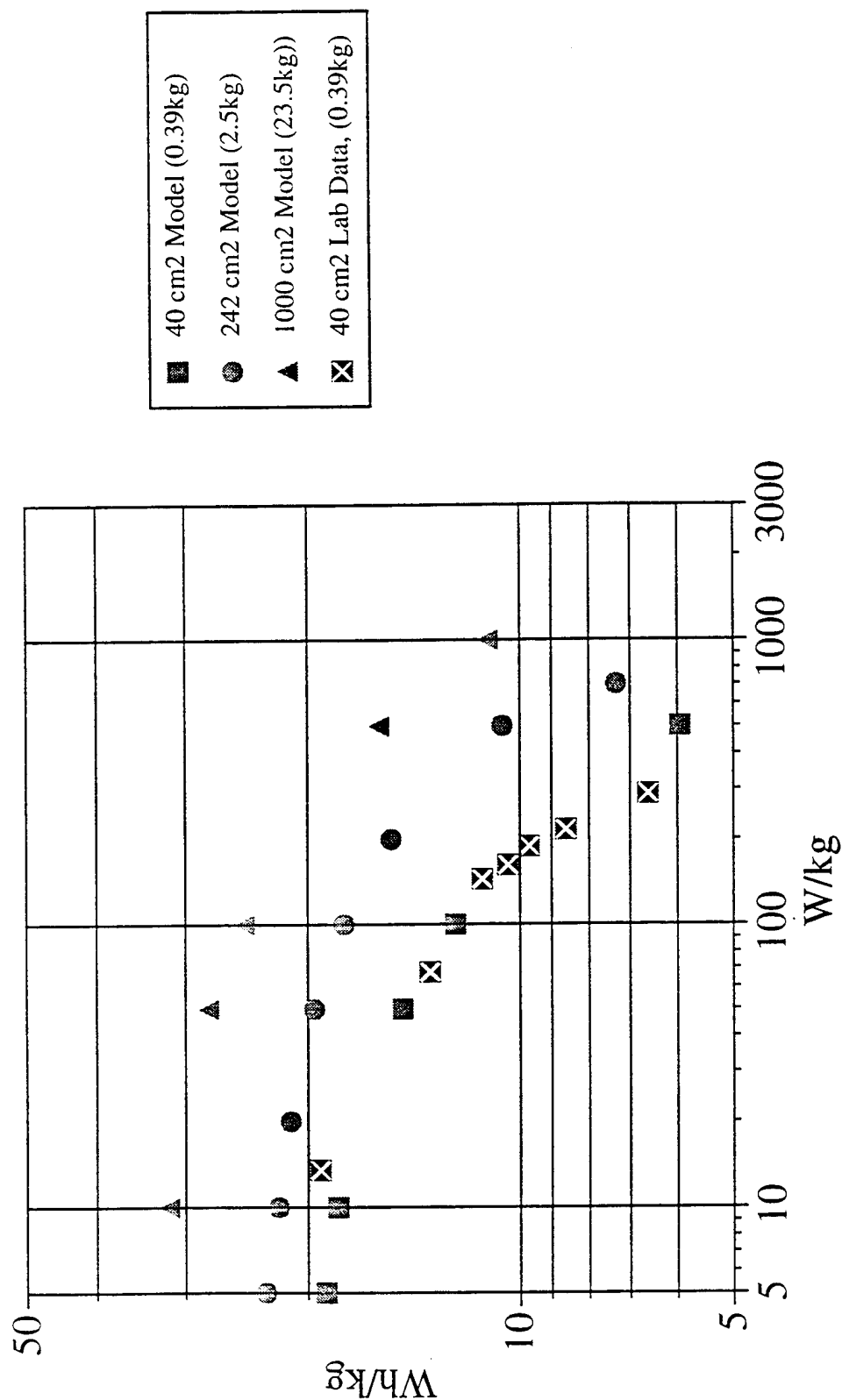


FIGURE 19  
Constant Power Performance Projections  
Metallic Bipolar Substrate



performed at 70°C and a constant potential of 1.50 V until evidence of pinholes was noted, i.e., liquid in the back chamber or spikes on the current acceptance curve. Replicate samples were then run, pulled at points prior to breakthrough, and submitted for cross sectional photomicrographs to quantify the corrosion rate.

Comparing rates of all samples tested showed the corrosion resistance of laminates to be second only to that of a high silver content alloy. Batteries utilizing the clad material were assembled and tested, but performance was poor. Teardowns showed improper cleaning of the starting materials to have prevented bonding of the dissimilar metals at the molecular level. Delamination resulted in high internal resistance that impeded high rate performance.

In October 1994, assistance was sought from Texas Instruments' Cladding Division (TICD), a leader in the laminating industry. Partnership activities were slow to materialize due to reorganization within TICD, however, two- and three-layer trials cladding lead to a stainless steel core were successful in December 1994. In March 1995, lead clad copper material was received and forwarded to Vacco Industries (see Metallic Substrate Work, Subtask 3.2) for surface etching trials. TI had planned bonding and rolling to facilitate a 65% reduction of the 0.054" thick constituent layers, however, a maximum of 51% was achieved before "chattering" (rippling) was observed. Secondary rolling ruined the bonds achieved in the first pass. New starting materials were requested for the production of 0.013" thick material, but the May delivery date made it unlikely that the laminated material would be available for use as the bipolar substrate in the required deliverables. Four layered, 0.032" thick sample material was received in June, and required reducing the copper core thickness by 50%. The likelihood of having the concept ready for deliverable use then dismissed.

#### 4.3.2 Subtask 3.2 Rolling/Embossing Work

Fostering paste adhesion to metal sheet requires the surface to be roughened in some manner. Small-scale metallic substrates possessed exemplary adhesion when hot pressed in a mold to create ribs protruding from each face. The raised pattern successfully broke up the "single paste pellet" that would otherwise sheet off the lead substrate during handling, and increased the surface area biting into the active material.

Substrate production times were slow and scale up required the use of more tonnage than available on any in-house press. It also lacked promise as a high speed, manufacturing process. A roller die was ordered and five hundred pounds of 0.020", 0.025" and 0.030" thick lead were delivered to MP Metal Products for rolling trials. Without authorization, MP turned to blanking the electrodes from a compression die when the first rolling trial was unsuccessful. Rolled

samples were never provided to JCBGI for evaluation. When informed of the new production direction, JCBGI reiterated their interest in the rolled concept, but conceded to whatever parts could be produced. Time was short. MP continued their effort to produce parts, but quickly found their press tonnage insufficient. Hence, a new vendor was located. Walking 300 tons force across the die produced acceptable parts from 0.020" thick starting material. Efforts to reduce the substrate thickness to the required 0.012" thickness were unsuccessful and the embossing effort abandoned.

Photochemical etching was investigated in conjunction with laminating activities (Metallic Development Work: Subtask 3.3.1). Early trials produced copper pieces that were electroplated with lead, pasted and shown to possess good adhesion. Solid lead sheet was not etched as easily, requiring strong chemicals that made the technique cost prohibitive (\$58/piece).

As backup, plastic screen was used. Pieces were cut to the size of the active material area, pressed to eliminate elevated nodes that could cause shorting through the separator, and were tacked to the lead substrate. This alternative eliminated roughly 240 grams of lead rib mass per battery, but required significantly more labor input than the embossing concept. Despite its facilitating acceptable results, the use of plastic screen is not recommended for manufacturing.

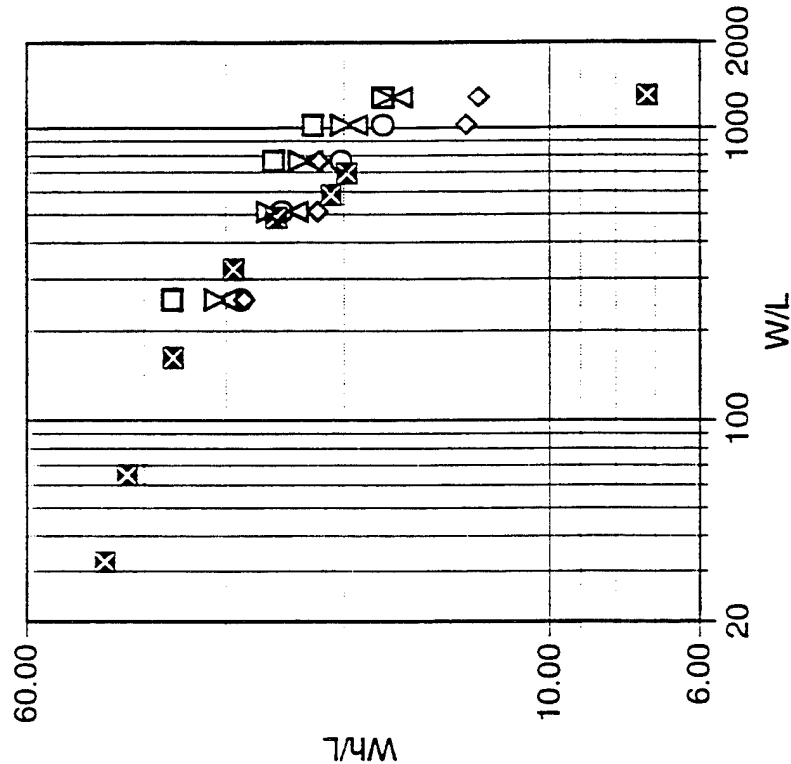
#### 4.3.3 Subtask 3.3 Substrate Corrosion Testing

Laminates received from Texas Instruments were never corrosion tested due to their being too thick.

#### 4.3.4 Subtask 3.4 Small Scale Characterization

Bipolar batteries having 0.012" thick substrates and 0.030" thick pasted layers were assembled, formed and tested in January 1995. Constant power discharge performance plots normalized to battery mass and volume are shown in Figure 20. Performance by WP2 and WP6 represented the best of the lot and greatly exceeded that reported for batteries delivered under the parallel metallic bipolar development contract. This was attributed to the use of 1.265 sg fill/form electrolyte. Reproducibility was an issue and investigated. Teardowns showed sulfated positives and dull negatives. Cured paste analyses reported consistently high levels of free lead that could cause initially poor or rapidly declining performance. A review of pasting procedures showed the starting PbO to be within specification and the paste code to be adequately sulfated

FIGURE 20



and consistent from mix to mix. The dry bulb within the curing chamber was found cracked and was repaired prior to further assembly operations.

Testing of four newly-formed 12-volt units showed 10-15 cycles at 100 W/kg to be necessary to reach full capacity. Discharge times were tightly grouped after formation (Figure 21). WP-12 lagged due to oxygen ingress at cycle 3. A cursory investigation of constant current rates (Figure 22) was performed to give insight into the constant power rates required per the test plan. Constant power performance was plotted along with the modeling prediction in Figure 23, then translated into the time versus power curve shown in Figure 24.

#### 4.4 WBS 4.0 BATTERY COMPONENTS

##### 4.4.1 Subtask 4.2 Active Material Development

Procedures and equipment were reviewed when the free lead content in positive and negative cured plates was reported at 5.5 and 10%, respectively - far above the 4% maximum. Increasing the curing residence time from 16 to 40 hours had little effect. Moisture content was found low (6-7%) as referenced to industry and company standards and, subsequently, paste code and plate handling techniques were reviewed. Efforts to keep plates moist while awaiting transport to the curing chamber only slowed the cure reactions and actually increased the cured free lead content. Lastly, the ABR humidity chamber was diagnosed with a cracked dry bulb, repaired and reset. Cured positive and negative plates from eight subsequent pasting runs displayed acceptable free lead content following a 24 hour residence time in the environmental chamber.

A limited investigation into the effects of freezing and thawing a small 12-volt battery was performed. One unit was tested at room temperature to establish a baseline capacity and then chilled to -60°C. A 5-hour thaw was allowed and the discharge test repeated. Evidence of cell reversal and a 13% capacity loss was documented. Confirmatory work was placed on hold to allow pasting, stacking and debugging of the formation techniques proposed for full-size, 24-volt units.

#### 4.5 WBS 5.0 BATTERY FABRICATION

##### 4.5.1 Subtask 5.1 Sealing Methods

A variety of compounds was evaluated for use in achieving a hermetic cell-to-cell seal. In the end, an engineering sample of hot melt adhesive was pressed between release paper into

FIGURE 21  
Small Scale Characterization  
Capacity Development, 24 deg C

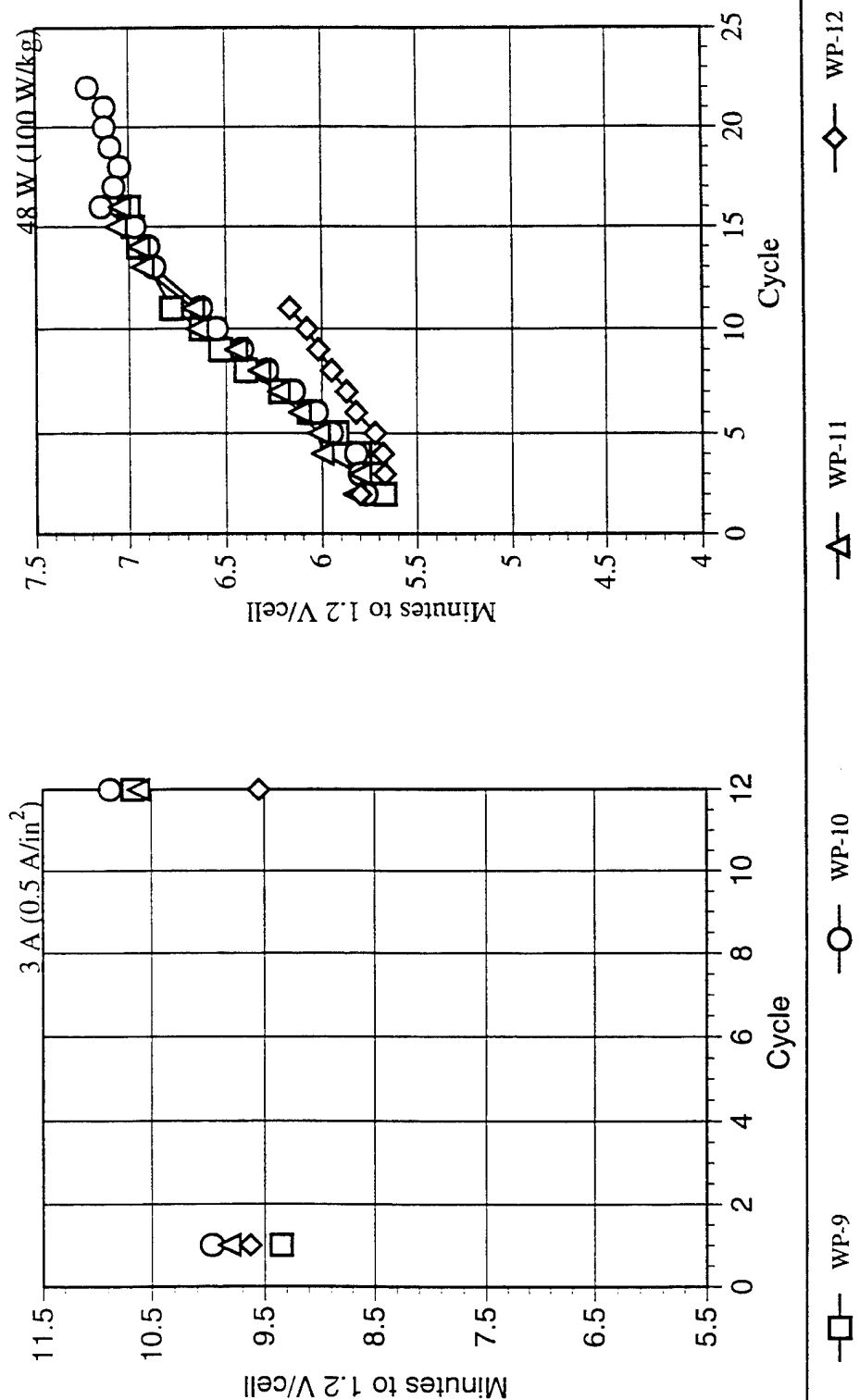




FIGURE 22

Small Scale Characterization  
Peukert Relationship, 24 deg C

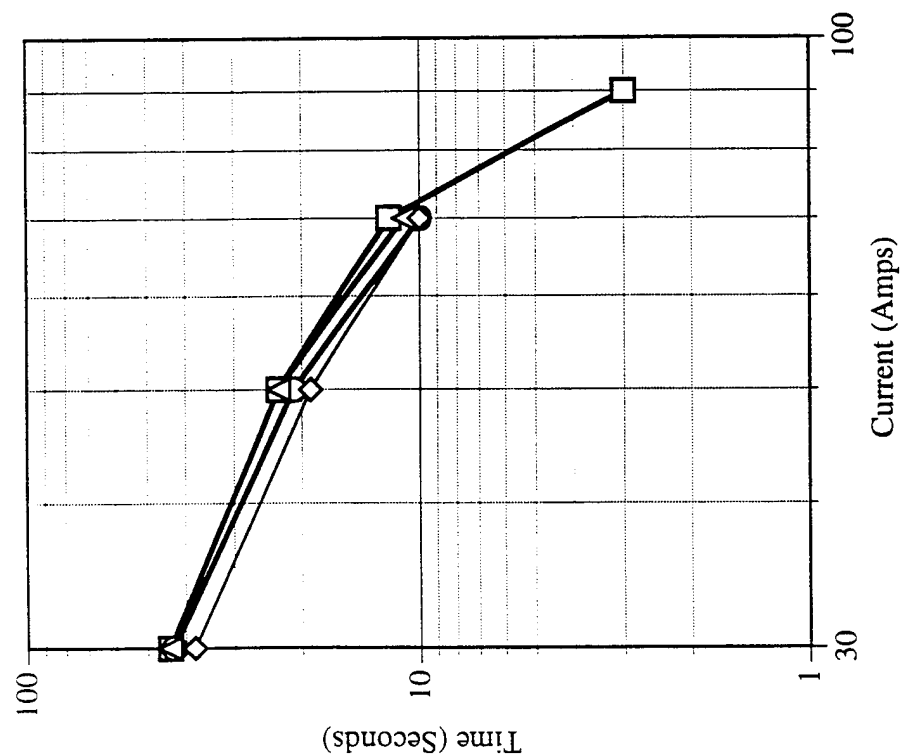
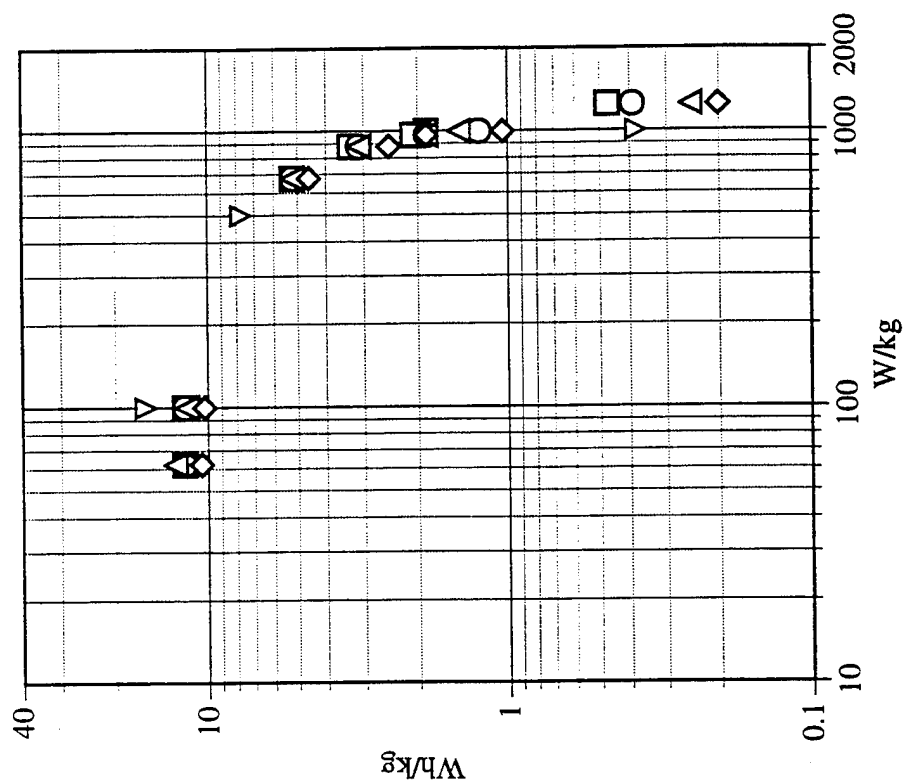
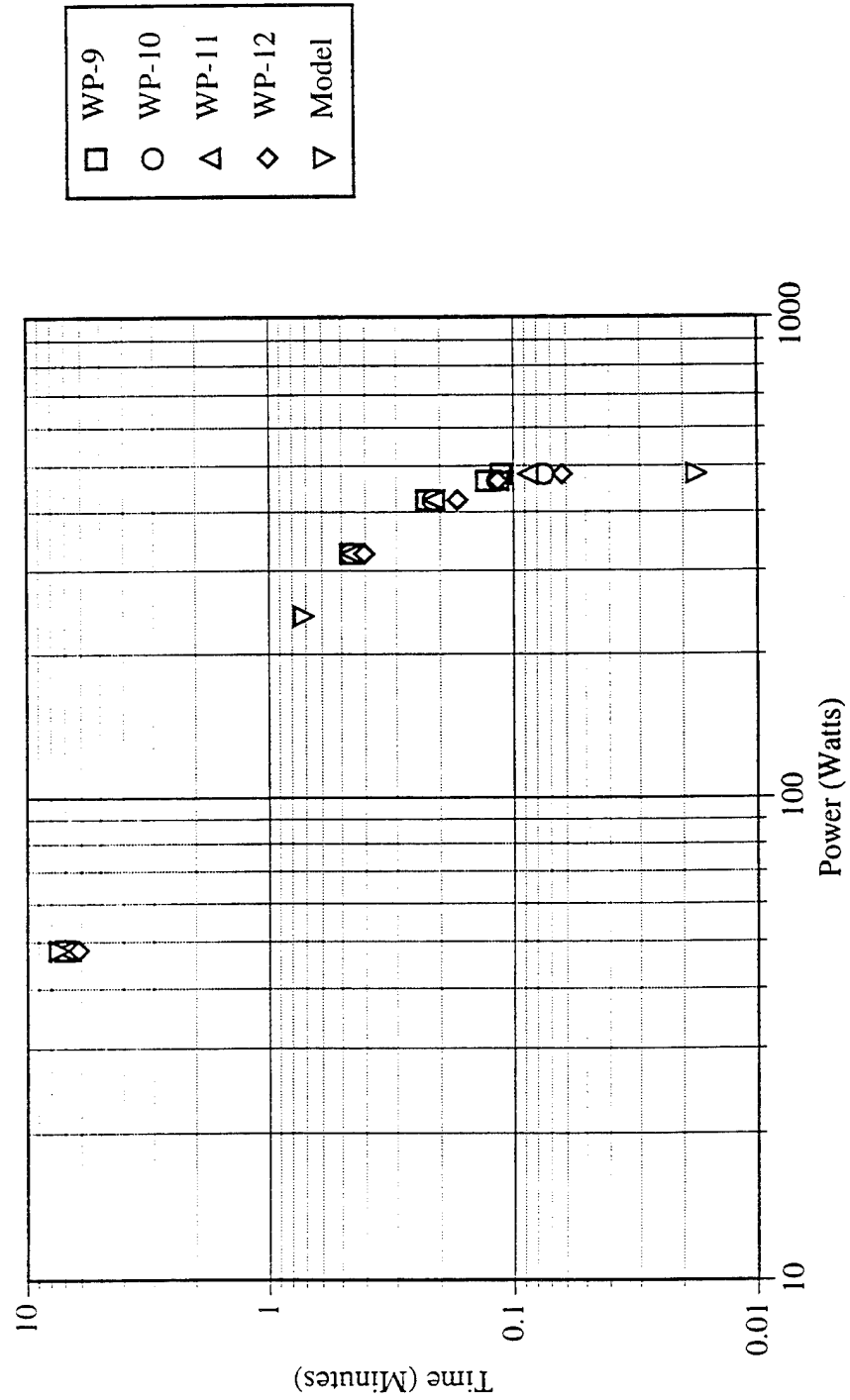


FIGURE 23  
Small Scale Characterization  
Ragone Relationship, 24 deg C



WP-9 WP-10 WP-11 WP-12 Model

FIGURE 24  
 Small Scale Characterization  
 Discharge Time vs Power, 24 deg C



sheet, chilled, slit into ribbon, chilled again, and finally laid onto treated plastic spacer frames. Dummy stacks were leak-free to 4 psig, and successfully completed 4 hours of intermittent vacuum pulsing to simulate the fill and form procedure. Cells in 12- and 24-volt stacks were also leak-free when similarly tested.

Sufficient quantities of the engineering sample material resided in-house, but efforts to find a replacement adhesive were initiated when additional material could no longer be obtained. Chemical analyses and physical testing of the original material was requested of H.B. Fuller and resulted in their furnishing two candidate replacement materials. Stack assembly showed one sample to be tackier and both materials able to withstand the level of vacuum required for filling. No further work with these substitutes was carried out since sufficient adhesive existed to complete the contract.

#### 4.5.2 Subtask 5.2 Formation

Two 24-volt batteries were stacked for formation studies. Each was comprised of 13 electrodes, 12 spacer frames, and two copper termination plates bolted between polycarbonate endwalls and outfitted with polycarbonate filling manifolds across each set of top slots.

Air pressurization of the first stack prior to filling showed one of the two fill ports to be leaking. The manifold was removed and the slots closed off after repeated attempts to seal the manifold were unsuccessful. Seventy-five minutes were required to input 300 cc of chilled electrolyte through the remaining manifold. This represented roughly 72% of the available void volume in the stack. Complete (100%) saturation had been targeted, however, small leaks developed around the base of the manifold, decreasing the fill efficiency. Current was applied for 120 minutes when evidence of shorting was apparent. Disassembly showed the majority of cells to have dendritic shorting through the center area of the separator. Failure was attributed to the long fill time (10-15 minutes was targeted to minimize the dissolution and diffusion of lead into the separator) and out-of-spec plate thicknesses. On average, plates were 0.007" over the 0.025" target, resulting in a compressed separator allowance of 0.016". Roughly 0.020" was considered the minimum separator thickness. Paste weights were reduced for the subsequent build.

The second 24-volt battery was assembled into a bolted polycarbonate fixture, filled to 84% saturation with chilled electrolyte, and placed on formation. Further filling risked lead dissolution and dendrite formation in the separator due to the excessive time required. Five cells shorted during formation as a result of a common electrolyte path along the lead exposed within the fill channel. Further formation attempts were placed on hold pending receipt of a molded stack which, by design, better guarded against common electrolyte paths in the fill port area.

## 4.6 WBS 6.0 BMET DEMONSTRATION

### 4.6.1 Subtask 6.1 Deliverables

Injection molded containment about metallic substrates was aggressively pursued for the majority of the No-Cost Time Extension. Repeated trials ultimately succeeded in correcting recurrent frame and electrode distortion, however, hermetic cell-to-cell seals were not obtained. Stacks were never available for formation or for trials to attach covers via induction welding. As a result, a backup battery design was implemented to complete the contract's deliverable requirements.

The following section describes the injection molded containment work in more detail, along with the proposed venting and intermodule connector concepts. The subtask is then concluded with a description of the batteries delivered to WPAFB.

#### 4.6.1.2 24-Volt Injection Molded Containment

The use of the injection molded containment concept previously tested with composite electrodes required one design modification to facilitate use with metallic substrates. To prevent distortion of the 0.012" thick metal electrode, the outer edge of the spacer frame was reshaped to wrap around the lead sheet and afford protection against the injection pressure. Glass filler was also added to the spacer resin to promote a melt bond with the outer endwalls. Molded spacers showed that shrinkage of the 0.082" thick parts was less than anticipated (0.003 in/in vs. 0.007 in/in). This was due to the ASTM shrinkage rate reporting basis (0.125"x0.5"x6" sample). As a result, spacers were slightly larger than specified, however, down-the-line assembly problems were not encountered.

The endwall material was also reevaluated and three candidates tested for use in maintaining the compressed stack dimension. Single layers of honeycombed aluminum sheet stock failed deflection testing. Bulk molding compound manufactured by Luvdahl provided the needed strength against a 6 psig load but was incompatible with battery acid. Glass-filled polypropylene was ultimately used after measuring a deflection of 0.013" at 5 psig.

Severely warped endwalls were produced during the first mold trial. Mold gate changes reduced the distortion, but a subsequent heat soak was still necessary to produce a flat part. Limited success was had in adding a blowing agent. Topical sinks located around the outer perimeter and the center termination port were greatly reduced but not eliminated. Slight part warpage also remained. Cross sectioning showed the internal pore size (caused by the blowing agent) to be very small. It also showed a 4-hour heat treatment to cure the warpage with no sign

of reactivating the blowing agent, but at the expense of the recessed terminal electrode cavity dimension. Heat treating was abandoned when measurements showed shrinkage along the length and width centerlines to be so great as to make it impossible to insert the terminal electrode in the recessed cavity.

Endwalls and spacers were then assembled with lead sheet to create dummy stacks for mold trials. Early attempts showed the plastic to distort the 10% glass frames inward toward the pasted portion of the stack, leaving insufficient material to fill the outer frame. Gate modifications were implemented in an effort to equalize the injection pressures at various points within the container mold. Center/side gating achieved complete mold fill and eliminated much of the frame distortion, however, cross-sectioning still showed buckled lead and uneven plastic distribution. The mold clamp location was then widened and additional glass added to the spacer resin for strength.

Strengthened plastic battery components were received and set up parts prepared for a trial in mid-July, 1995. Glass loading in the frame was increased to 30% in order to prevent blowing in and lead distortion, and to reduce part compression when clamped within the mold. The molding trial was nearly successful. Complete mold fill was achieved with slight crowning of the frames. A "clamp only" trial showed the crowning to be a result of the mold closing. Still closer examination revealed the stacks loaded into the mold to be ~0.100" too thick as a result of out-of-spec adhesive. The remaining thick stacks were preheated and easily compressed to the correct 1.454" thick dimension. Disassembly showed no electrode distortion. Laboratory measurements of stacks assembled using 0.003" thick adhesive (a 50% reduction) were similarly flat.

The subsequent molding trial with correctly processed adhesive produced four dummy stacks and one DUF battery for analysis. Electrodes in all four dummy stacks were distorted along the inner frame perimeter. Heat sensitive indicators inserted at two points in each stack recorded the temperature history and showed no indication of having reached the temperature at which the inlaid adhesive would begin to flow.

The distortion was subsequently eliminated in late July by thermally fusing the outer edges of the stack to better resist the high molding pressure. Pressure testing to confirm cell-to-cell seals identified leakage that was traced to the area surrounding the fill channels. Close examination showed a lack of melt bond between the prefused frame and injected containment plastic. Given the cost and time associated with the mold change proposed to eliminate the leakage, the concept was abandoned for use with WPAFB deliverables.

Venting considerations were evaluated concurrently to stack molding. Implementation of a totally sealed design was initially considered, but dismissed. Utilizing a fail-safe panel along

the face representing the endwall would have reduced its functionality as a means of maintaining adequate battery compression. User safety in the event of an abusive overcharge was an even greater concern.

A review of available off-the-shelf vents quickly showed that no battery vent supplier had ever addressed the main issue facing bipolar technology: cell width. Vent designs just 0.060" to 0.080" in width did not exist. Staggering the vents was proposed, but eliminated from further consideration when it became apparent that multiple frame molds would be required.

Having limited data showing success in cycling a small bipolar battery utilizing single point venting, the deliverable venting configuration was drawn. In its final form, a 24-volt battery was to be fitted with a vent over each of the fill slot locations. This duplicity provided a backup venting location to any cell that might incur blockage in one of its ports. Oil applied topically aided in achieving and maintaining the hermetic seal required for recombinant, maintenance-free operation.

Two methods were suggested for attaching the vent/cover to the injection molded battery housing: heat sealing and induction welding.

Heat sealing is used throughout the battery industry. Generally, this involves heating the edges to be joined, bringing them into contact, and allowing them to cool under pressure. Concern was raised over being able to hold the 0.080" thick cover while preheating it with a heat lamp. That and the estimated \$30,000 to build a suitable machine to try the concept made heat sealing a last choice technique.

Induction welding was then investigated. This process was reportedly fast and versatile. Heat induced by a high frequency electrodynamic field in a metallic insert placed at the joint brings the surrounding material to the melt temperature. Pressure maintained as the field is turned off maintains the joint as it solidifies. Welding occurs only in the area immediately adjacent to the metallic insert. As a result, weld strength depends on the size and geometry of the metal insert.

The process was also feasible economically. Purchasing a new laboratory unit required \$10,000. Leasing was also possible at \$750 per month.

Initial induction welded samples prepared by Pillar Industries indicated that a hermetic bond could be easily achieved around the periphery of the vent/cover. A semicircular cavity rimming the upper edge of the battery and the two cross bars spanning the center portion of the upper surface was included in the mold design. Later testing proved that a hermetic bond along the cross bars would not be achieved. Mold changes were ordered to reduce the cross bar height to make them serve only as structural supports. Hermetic seals at these points were not necessary given the remainder of the cover weld met specification. Test welds with stacks and covers were never attempted given the difficulties previously described.

Lastly, NCTE work was performed to efficiently connect two 24-volt units in series to form a higher voltage subassembly. Various porous copper samples were obtained and tested under load. Results showed the porous copper to be less resistive than solid copper sheet wrapped around a foam pad (Figure 25). Twenty pieces of 60 pores per inch (ppi) material were ordered and received on time, but never used in deliverables. The batteries delivered utilized a backup containment design that facilitated direct assembly of higher voltage stacks.

#### 4.6.1.3 Gasketed Containment

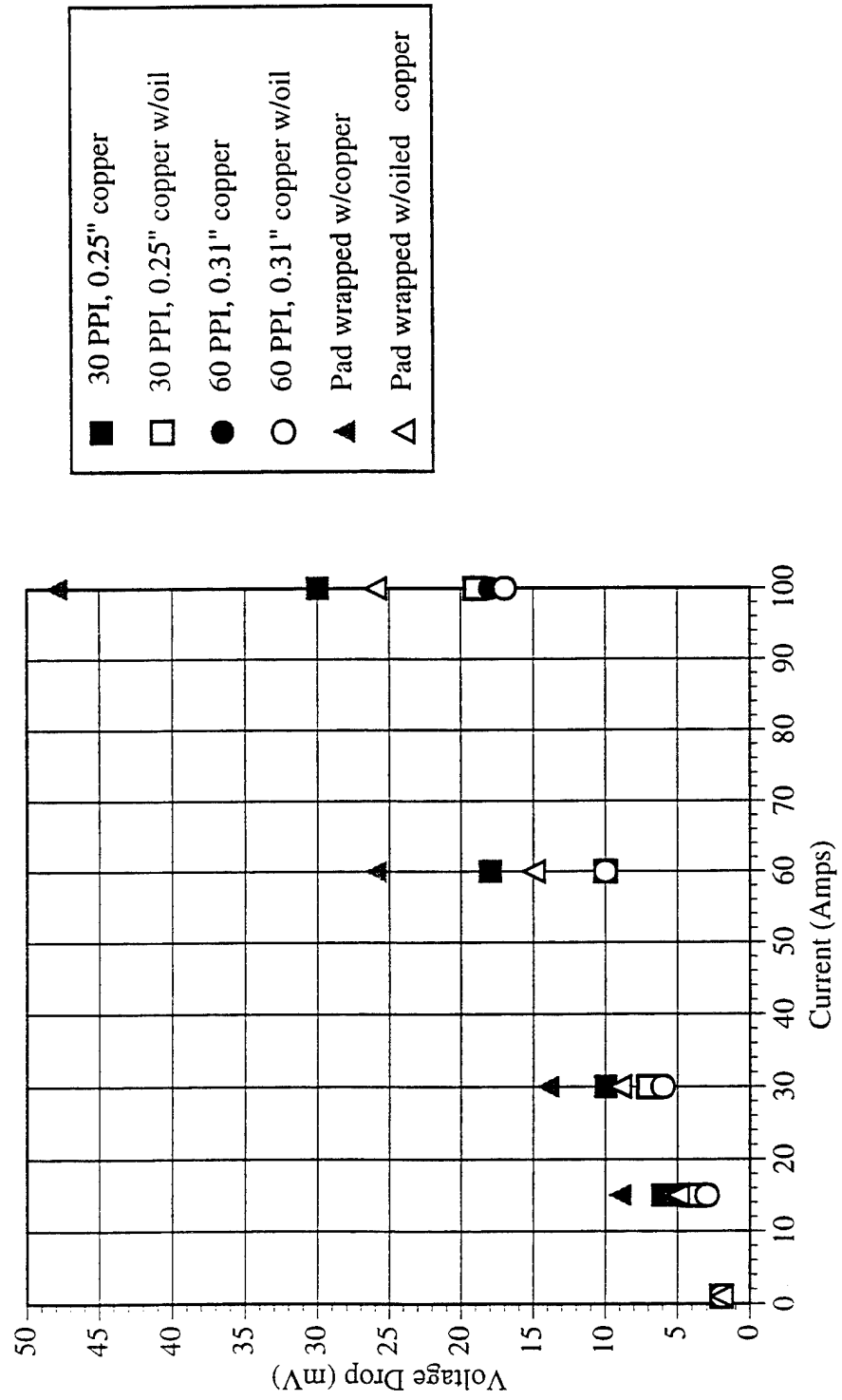
Given the difficulties encountered in achieving hermetic cell-to-cell seals with the injection molded containment concept, WPAFB accepted deliverable batteries assembled using neoprene spacers and machined ABS container components (Appendix B).

Bipolar electrode substrates were die cut from 0.012" thick tin-lead sheet and pasted following the attachment of plastic screen (see Metallic Substrate Development, Subtask 3.3.2). Three paste runs succeeded in pinpointing the wet paste weight needed to achieve the targeted 0.062" electrode thickness. After curing and drying, plates were individually cleaned, weighed, and checked for high spots (thickness). Paste mass and thicknesses of bipolar electrodes used in the deliverable candidates were put at  $105.7 \pm 2.5$  grams and  $0.059 \pm 0.001$ ", respectively.

Terminal electrodes were die cut from laminated sheet stock comprised of 0.008" thick lead and 0.014" thick copper. This design permitted copper terminations to be soldered to the copper face of the electrode with minimal risk of burning a pinhole through the lead face. Each 0.75" long x 0.75" OD stud with a tapped thread was correctly located by first soldering it to an oversized electrode that was then die-cut to achieve the required dead-center location. (This procedure had been critical to injection mold trials since the stack position in the mold was based on the stud location.) Stud welds were shown to withstand an average of 285 in-lb of torque before failing at the solder-to-laminate joint. This compared favorably to the 180 in-lb SLI specification.

Container components were machined from 0.125" and 0.250" (nominal) thick ABS. Solvent bonding was implemented to join the pieces. Endwalls were provided the necessary strength by encapsulating multiple sheets of honeycombed aluminum within a protective ABS cavity. Electrodes were sequentially placed onto neoprene gaskets and absorptive glass mat positioned over the active area to prevent shorting. Separator material was sized to overlap the active area slightly. Starting thickness facilitated the 25% compression deemed critical to supporting high rates of discharge. Fittings were located in channels milled into each gasket to create ports for filling and venting.

FIGURE 25  
Voltage Drop Across Intermodule Connector Candidate Materials





Fill and formation were attempted only after confirming each and every cell in a stack to be leak free. Filling was accomplished by evacuating the cells through a column of chilled electrolyte. Returning the system above the electrolyte to atmospheric pressure forced the predetermined volume of acid into each cell quickly and efficiently. Internal stack temperature was monitored constantly and used in controlling the formation current. Current was applied as soon as the fill was completed to minimize the risk of dendritic shorting due to lead dissolution.

Fittings were removed and the cover/vent assembly solvent bonded into place after limited qualification cycling was performed to fully develop the capacity. Details regarding the assembly, formation, and qualification testing of each deliverable are included in Appendix B.

To assist WPAFB in preparing for receipt of these units, three bound copies of safety instructions and operating recommendations were mailed February 29, 1996. One 24-volt and two 12-volt nominal batteries were hand delivered to Wright Laboratory on March 6, 1996 with an additional two copies of the instructions and recommendations. Identification and safety labels were attached to each battery to warn of the potential for explosion, acid burns and electrical shock.

## APPENDIX A

### RESISTIVITY TESTING

## RESISTIVITY TESTING

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM) BEFORE	THICKNESS (INCH) BEFORE	RESISTIVITY (OHM-CM) BEFORE	RESISTANCE (OHM) AFTER	THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
47A	4/2/92	LAMINATED 85% GC23N W/O CA 15% MICROTHENE 4.5 M.I. C-PLASTIC	0.365 0.450 0.270 6.084	0.023 0.024 0.023	6.248 7.382 4.622 6.084	0.960 0.640 1.060	0.042 0.042 0.042	8.999 5.999 9.936 8.311	36.6158656
48A	4/2/92	LAMINATED 85% GC23N WITH CA 15% MICROTHENE 4.5 M.I. C-PLASTIC	0.630 0.570 0.635	0.025 0.024 0.024	9.921 9.350 10.417 9.896	1.000 1.500 0.740	0.040 0.040 0.040	9.843 14.764 7.283 10.630	7.415184
52	4/9/92	LAMINATED 84% GC23N & 16%PTFE TO C-PLASTIC & Pb FOIL SINGLE APPLICATION OF RESIN	1.180	0.053	8.765	19.500 17.500 38.000	0.062 0.062 0.063	123.825 111.125 237.470 157.474	1696.53351
53	4/9/92	LAMINATED 84% GC23N & 16%PTFE TO C-PLASTIC & Pb FOIL DOUBLE APPLICATION OF RESIN	3.630	0.061	23.428	169.000 161.000 188.000	0.054 0.054 0.054	1232.138 1173.812 1370.662 1258.870	5273.26123
54B	4/14/92	LAMINATED 85% GC23N-1 15% MICROTHENE 4.5 M.I. WITH Pb FOIL	0.195	0.040	1.919	0.440 0.483 0.470	0.040 0.040 0.040	4.331 4.754 4.626 4.570	138.119658
55B	4/14/92	LAMINATED 85% GC23N-2 15% MICROTHENE 4.5 M.I. W/O pb FOIL	0.250	0.030	3.281	1.730 2.350 3.600	0.030 0.030 0.030	22.703 30.840 47.244 33.596	924
71A	4/24/92	LAMINATED THICK/THICK GC23N-1 /C-PLASTIC	0.295 0.300 0.280	0.206 0.208 0.208	0.564 0.568 0.530 0.554	0.390 0.430 0.400	0.209 0.211 0.208	0.735 0.802 0.757 0.765	38.0646797
72A	4/24/92	LAMINATED THIN/THIN GC23N-2 /C-PLASTIC	0.275 0.265 0.275	0.208 0.208 0.207	0.521 0.502 0.523 0.515	0.495 0.410 0.500	0.210 0.210 0.209	0.928 0.769 0.942 0.880	70.763192
73A	4/24/92	LAMINATED THICK/THIN GC23N-3 /C-PLASTIC	0.420 0.250 0.220	0.031 0.032 0.033	5.334 3.076 2.625 3.678	3.800 8.800 6.400	0.031 0.031 0.032	48.260 111.760 78.740 79.587	2063.76933

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE		THICKNESS		RESISTIVITY		RESISTANCE		THICKNESS		RESISTIVITY		PERCENT CHANGE
			(OHM) BEFORE	(OHM) AFTER	(INCH) BEFORE	(INCH) AFTER	(OHM-CM) BEFORE	(OHM-CM) AFTER	(OHM) BEFORE	(OHM) AFTER	(INCH) BEFORE	(INCH) AFTER	(OHM-CM) BEFORE	(OHM-CM) AFTER	
74A	4/24/92	LAMINATED	0.380	0.380	0.032	0.032	4.675	4.300	4.300	4.300	0.032	0.032	52.904	52.904	1079.12921
		THIN/THIN	0.440	0.440	0.033	0.033	5.249	5.100	5.100	5.100	0.033	0.033	60.845	60.845	
		GC23N-4 /C-PLASTIC	0.430	0.430	0.031	0.031	5.461	5.500	5.500	5.500	0.032	0.032	67.667	67.667	
75A	4/24/92	LAMINATED	0.350	0.350	0.121	0.121	1.139	0.570	0.570	0.570	0.122	0.122	1.839	1.839	15.9055035
		THICK/THIN	0.580	0.580	0.122	0.122	1.872	0.520	0.520	0.520	0.123	0.123	1.664	1.664	
		GC23N-5 /C-PLASTIC	0.280	0.280	0.123	0.123	0.896	0.320	0.320	0.320	0.123	0.123	1.024	1.024	
76A	4/24/92	LAMINATED	0.285	0.285	0.124	0.124	0.905	2.350	2.350	2.350	0.125	0.125	7.402	7.402	780.24688
		THIN/THICK	0.275	0.275	0.126	0.126	0.859	2.580	2.580	2.580	0.124	0.124	8.192	8.192	
		GC23N-6 /C-PLASTIC	0.270	0.270	0.126	0.126	0.844	2.300	2.300	2.300	0.123	0.123	7.362	7.362	
77A	5/12/92	LAMINATED	0.36	0.36	0.026	0.026	5.451								
		GC23N-A-3/92													
		Pb-FOIL													
78A	6/5/92	LAMINATED	0.22	0.22	0.026	0.026	3.331								
		GC23N-B-3/92													
		Pb-FOIL													
78A	6/5/92	LAMINATED	0.66	0.66	0.027	0.027	9.624								
		GC23N-MICROTHENE &													
		C-PLASTIC													
79A	5/20/92	LAMINATE	0.228	0.228	0.03	0.03	2.992	0.38	0.38	0.38	0.03	0.03	4.987	4.987	66.6666667
		GC23N-1-85% MICROTHENE/CA	0.185	0.185	0.03	0.03	2.428	5.8	5.8	5.8	0.03	0.03	76.115	76.115	
		GC23N-2-85% MICROTHENE	0.21	0.21	0.027	0.027	3.062	0.66	0.66	0.66	0.028	0.028	9.280	9.280	
79A	5/20/92	LAMINATE	0.52	0.52	0.046	0.046	4.451	3.7	3.7	3.7	0.046	0.046	31.667	31.667	611.538462
		GC23N-1-85% MICROTHENE/CA	0.335	0.335	0.044	0.044	2.997	2.2	2.2	2.2	0.044	0.044	19.685	19.685	
		GC23N-2-85% MICROTHENE	0.49	0.49	0.039	0.039	4.946	21	21	21	0.041	0.041	201.652	201.652	
79A	5/20/92	LAMINATE	0.435	0.435	0.037	0.037	4.629	13.5	13.5	13.5	0.038	0.038	139.867	139.867	2921.77858
		GC23N-3-80.3% KY													
		GC23N-4-80.3%													

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
80A	5/27/92  PG. 139/141	KY/CA									
		LAMINATE									
		GC23N-1-85%	0.36	0.445	0.04	0.04	3.543	0.445	0.04	4.380	23.6111111
		MICROTHENE/CA									
		GC23N-2-85%	0.495	0.525	0.039	0.038	4.997	0.525	0.038	5.439	8.85167464
		MICROTHENE									
		GC23N-3-80.3%	0.223	0.253	0.044	0.044	1.995	0.253	0.044	2.264	13.4529148
		KY									
81A	6/9/92	GC23N-4-80.3%	0.305	0.35	0.042	0.041	2.859	0.35	0.041	3.361	17.5529788
		KY/CA									
		LAMINATED									
		GC23N-MICROTHENE & C-PLASTIC									
		5/92-1R									
		5/92-2R									
		5/92-3R									
		5/92-4R									
82A	6/10/92	LAMINATED									
		DOPED OXIDE/SCW AND C-PLASTIC	0.38	23.3	0.098	0.098	1.527	23.3	0.098	93.604	6031.57895
84A	6/26/92	LAMINATED									
		DOPED OXIDE-5/92									
		KY 7201 & 711									
		C-PLASTIC									
		CA									
		70%-7201	1.7	26.3	0.031	0.031	21.590	26.3	0.031	334.011	1447.05882
		75%-7201	0.54	220	0.031	0.033	6.858	220	0.033	2624.672	38171.6049
		85%-711	0.45	3.003	0.059	0.031	3.003	1.75	0.031	22.225	130.121225
		70%-7201 & CA	0.785	9.658	0.032	0.032	9.658	6.4	0.032	78.740	870.588235
		75%-7201 & CA	0.68	8.113	0.033	0.032	8.113	6.4	0.032	78.740	870.588235
85A	6/30/92	85%-711 & CA	0.32	2.032	0.062	0.032	2.032				
		LAMINATES									
		DOPED OXIDE, CA									
		C-PLASTIC, Pb FOIL									
		711 KYANR & Pb DUST									
		70%-W/CA-FOIL	3.7	66.213	0.022	0.025	66.213	71.5	0.025	1125.984	22243.75
		70%-W/CA-DUST	0.6	10.737	0.022	0.025	10.737	12	0.025	188.976	11776.2887
		70%-W/O CA-FOIL	2.15	38.475	0.022	0.024	38.475	73	0.026	1105.391	15570.8408
		70%-W/O CA-DUST	0.32	5.039	0.025	0.024	5.039	12	0.025	188.976	11776.2887
		75%-W/CA-FOIL	0.097	1.591	0.024	0.024	1.591	73	0.026	1105.391	15570.8408
		75%-W/CA-DUST	0.43	7.054	0.024	0.024	7.054				
		75%-W/O CA-FOIL	1.25	19.685	0.025	0.025	19.685				

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
88A	7/13/92	75%-W/O CA-DUST	0.3		0.026		4.543	70	0.028	984.252	21566.6667
		5/92-DOPED OXIDE KY-711									
		C-PLASTIC									
		013-C-PLASTIC	0.11		0.013		3.331	0.115	0.012	3.773	13.2575758
		020-DOPED OXIDE	0.65		0.033		7.755				
		030-DOPED OXIDE	1.15		0.042		10.780	3.85	0.042	36.089	234.782609
92A	7/22/92	040-DOPED OXIDE	1.55		0.05		12.205	1.13	0.048	9.268	-24.0591398
		050-DOPED OXIDE	1.65		0.054		12.030	1.68	0.054	12.248	181818182
		LEAD DUST & POLYSULFONE	0.043		0.028		0.605				
		PREMIXED W/1.1.1 DRIED PRESSED AT 599F 30 TONS 55% BY WT.									
		LAMINATE									
		DOPED OXIDE(S/92) KY-711 & KETWITH KY-711	0.305		0.068		1.766	0.48	0.068	2.779	57.3770492
94A	7/28/92	14%-KET/KYN-.050	0.38		0.061		2.453	0.4	0.061	2.582	5.26315789
		14%-KET/KYN-.040	0.5		0.051		3.860	0.74	0.051	5.713	48
		14%-KET/KYN-.030	0.066		0.025		1.039	0.57	0.025	8.976	763.636364
		PbPOLYSULFONE									
		LAMINATE									
		DOPED OXIDE(S/92) KY-7201 & KETWITH KY-7201	0.305		0.066		1.819	0.345	0.066	2.058	13.1147541
95A	7/30/92	14%-KET/KYN-.050	0.295		0.061		1.904	0.4	0.061	2.582	35.5932203
		14%-KET/KYN-.040	0.27		0.052		2.044	1.15	0.052	8.707	325.925926
		14%-KET/KYN-.030	0.255		0.043		2.335	4.2	0.043	38.454	1547.05882
		14%-KET/KYN-.020	0.243		0.047		2.036	SAMPLE	FOR	SHOW	
		14%-KET/KYN-.026									
		LAMINATES									
96A	8/10/92	DOPED OXIDE W/MICROTHENE KET & MICROTHENE									
		80%-DOPED OXIDE-96A-1	0.62		0.071		3.438	0.64	0.071	3.549	3.22580645
		80%-DOPED OXIDE-96A-2	0.46		0.063		2.875	0.44	0.063	2.750	-4.34782609

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
97A	8/18/92	LAMINATES							
		DOPED OXIDE/KY(8/92)							
		KET/KY(8/92)							
		75%-DOPED OXIDE-97A-1	0.21	1.65	0.052	0.052	1.590	12.492	685.714286
99A	8/21/92	LAMINATES							
		DOPED OXIDE/KY							
		KET/KY							
		75%-DOPED OXIDE-99A-1	0.25	0.31	0.074	0.074	1.330	1.649	24
102A	9/16/92	LAMINATES							
		DOPED OXIDE/MICROTHENE							
		KET/MICROTHENE							
		80%-DOPED OXIDE-102A-1	1.55	2.4	0.061	0.062	10.004	15.240	52.3413111
103A	9/23/92	LAMINATES							
		WASHED DOPED OXIDE							
		PRECOMFOUNDED							
		C-PLASTIC							
104A	9/29/92	LAMINATES							
		WASHED DOPED OXIDE							
		PRECOMFOUNDED							
		C-PLASTIC							
105A	10/9/92	LAMINATES							
		WASHED DOPED OXIDE							
		PRECOMFOUNDED							
		C-PLASTIC							

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
109A		80%-LOADING											
		DOPED OXIDE (5/92)											
		10%KY/90%MIC.-105A-1	0.17		0.056		1.195		0.056		0.45		164.705882
		20%KY/80%MIC.-105A-2	0.185		0.053		1.374		0.053		0.78		321.621622
		30%KY/70%MIC.-105A-3	0.173		0.053		1.285		0.053		1.85		969.364162
110A	10-26-92	40%KY/60%MIC.-105A-4	0.165		0.05		1.299		0.05		2.8		1596.9697
		KY (7/92) &											
		MICROTHENE (5/92)											
		80%-LOADING											
		DOPED OXIDE (5/92)											
110A	10-26-92	109A-1	0.29		0.041		2.785		0.04		0.87		141.666667
		109A-2	0.36		0.04		3.543		0.042		412.448		12915.873
		109A-3	0.33		0.041		3.169		0.041		8.162		83.7583149
		109A-4	0.44		0.039		4.442		0.041				
		LAMINATES											
111A	10/29/92	80% DOPED OXIDE(5/92)											
		MICRO.(5/92) &											
		KY(7/92)											
		110A-1	0.225		0.038		2.331		0.038		4.9		2077.77778
		110A-2	0.35		0.039		3.533		0.039		48.455		1271.42857
111A	10/29/92	110A-3	0.22		0.042		2.062		0.042		1.75		695.454545
		110A-4	0.33		0.041		3.169		0.041		0.57		72.7272727
		LAMINATES											
		PRECOMPOUNDED											
		MICRO./DOPED OXIDE											
112A	11/5/92	85%-LOADING											
		111A-1	1		0.042		9.374		0.042		1.95		95
		80%-LOADING											
		111A-2	2.1		0.043		19.227		0.043		3		42.8571429
		KY/DOPED OXIDE											
112A	11/5/92	75%-LOADING											
		111A-3	0.8		0.053		5.943		0.053		1.2		50
		MICRO./DOPED OXIDE											
		80%-LOADING											
		111A-4	1.8		0.036		19.685		0.036		2		11.1111111
112A	11/5/92	LAMINATES											
		75% LOADING											
		DOPED OXIDE(7/92)											
		KY(7/92)											
		14%KET(9/92)											
112A	11/5/92	KY(7/92)											
		112A-1	0.15		0.089		0.664		0.089		0.000		-100
		112A-2	0.165		0.088		0.738		0.088		0.000		-100
		400F/3 TONS											
		400F/3 TONS											



SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
113A	325F/3 TONS 11/10/92	LAMINATES 80% LOADING							
		DOPED OXIDE(7/92) MICROTHENE(5/92) PRECOMPOUNDED C-PLASTIC							
		112A-3	0.46		0.069	0.069	2.625	0.000	-100
		112A-4	0.58		0.075	0.075	3.045	0.000	-100
	325F/3 TONS 11/10/92	LAMINATES							
		80% DOPED OXIDE(7/92) MICROTHENE(5/92) CA							
		PRECOMPOUNDED C-PLASTIC							
		113A-1	0.49		0.064	0.064	3.014	28.912	859.183673
	325F/3 TONS 11/10/92	113A-2	0.37		0.066	0.066	2.207	27.440	1143.24324
		113A-3	0.36		0.074	0.074	1.915	4.522	136.11111
114A	325F/3 TONS 11/10/92	113A-4	0.41		0.068	0.068	2.374	4.111	73.1707317
		LAMINATES							
		80% DOPED OXIDE(7/92) MICROTHENE(5/92) CA							
		PRECOMPOUNDED C-PLASTIC							
	325F/3 TONS 11/24/92	114A-1	0.43		0.062	0.062	2.731	11.113	306.976744
		114A-2	0.42		0.069	0.069	2.396	7.760	223.809524
		114A-3	0.46		0.068	0.068	2.663	5.616	110.869565
		114A-4	0.64		0.076	0.076	3.315	5.439	64.0625
	325F/3 TONS 11/24/92	LAMINATES							
		80% LOADING DOPED OXIDE							
115A	325F/3 TONS	20% MICROTHENE							
		WASHING TECH. PRECOMPOUNDED C-PLASTIC .2%/07GMS CA							
		325F/3 TONS	0.38		0.073	0.072	2.049	2.843	38.7426901
		115A-1 COARSE-X	0.52		0.072	0.072	2.843	2.843	38.7426901

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
116A	325F/3 TONS	115A-2 COARSE-X	0.35		0.072		1.914		0.52		0.072		2.843	48.5714286
	325F/3 TONS	115A-3 MEDIUM-X	0.46		0.062		2.921		0.96		0.062		6.096	108.695652
	325F/3 TONS	115A-4 MEDIUM-X	0.58		0.067		3.408		1.18		0.067		6.934	103.448276
	11/25/92	LAMINATES												
80% LOADING DOPED OXIDE														
20% MICROETHENE														
PRECOMPOUNDED C-PLASTIC														
2%/07GMS CA														
	325F/3 TONS	116A-1 COARSE	0.37		0.077		1.892							
	325F/3 TONS	116A-2 COARSE	0.3		0.071		1.664							
	325F/3 TONS	116A-3 MEDIUM	0.88		0.067		5.171							
	325F/3 TONS	116A-4 MEDIUM	0.61		0.066		3.639							
117A	12/03/92	LAMINATES												
		80% LOADING DOPED OXIDE												
		20% MICROETHENE												
		PRECOMPOUNDED C-PLASTIC												
.15% TO .45% CA														
	325F/3 TONS	117-1A (.15%)	0.38		0.071		2.107		0.98		0.071		5.434	157.894737
	117-2A (.20%)	117-2A (.20%)	0.51		0.071		2.828		1.15		0.071		6.377	125.490196
	117-3A (.25%)	117-3A (.25%)	0.42		0.068		2.432		0.7		0.066		4.176	71.7171717
	117-4A (.30%)	117-4A (.30%)	0.56		0.068		3.242		0.98		0.068		5.674	75
	117-5A (.35%)	117-5A (.35%)	0.42		0.071		2.329							
	117-6A (.40%)	117-6A (.40%)	0.46		0.065		2.786							
	117-7A (.45%)	117-7A (.45%)	0.64		0.064		3.937							
	12/07/92	LAMINATES												
80% LOADING DOPED OXIDE														
20% MICROETHENE														
PRECOMPOUNDED C-PLASTIC														
.15% TO .45% CA														
	325F/3 TONS	118-1A (.15%)	0.4		0.068		2.316							
	118-1A (.15%)	118-1A (.15%)												

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
119A	12/04/92 119A	118-2A (.20%)	0.4		0.071		2.218								
		118-3A (.25%)	0.38		0.068		2.200								
		118-4A (.30%)	0.33		0.068		1.911		0.4		0.069		2.282		19.4554238
		118-5A (.35%)	0.3		0.068		1.737		0.4		0.067		2.350		35.3233831
		118-6A (.40%)	0.4		0.069		2.282		0.46		0.069		2.625		15
		118-7A (.45%)	0.36		0.068		2.084		0.45		0.068		2.605		25
		THIN LAMINATES 80% LOADING DOPED OXIDE													
120A	12/16/92	20% MICROTHENE PRECOMPOUNDED C-PLASTIC .25% CA 325F/3 TONS													
		119-1A	0.5		0.038		5.180								
		119-2A	0.34		0.038		3.523								
		119-3A	0.225		0.033		2.684								
		119-4A	0.42		0.03		5.512								
		HAND COMPOUNDED CARBON PLASTIC													
		120-1A 350F	0.43		0.058		2.919								
121A	12/17/92	120-2A 350F	0.51		0.061		3.292		0.52		0.059		3.470		36.8421053
		120-3A 375F	0.38		0.059		2.536		0.56		0.062		3.556		27.2727273
		120-4A 375F	0.44		0.062		2.794								
		PRECOMPOUNDED CARBON PLASTIC													
		120-5A	1.3		0.056		9.139		1.95		0.056		13.709		50
		120-6A	2.05		0.058		13.915		2.95		0.058		20.024		43.902439
		LAMINATES 80% LOADING DOPED OXIDE MICROTHENE (5/92) .25% CA HANDCOMPOUNDED CARBON PLASTIC													
122A	12/17/92	121-1A	0.43		0.075		2.257								
		121-2A	0.43		0.07		2.418								
		LAMINATES 2.60G KETBLACK 10.37G MICRO (5/92) 325F/15 TONS 0.060" SHIM													

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)	
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
123A	123A 01/04/93	LAMINATES 80% LOADING DOPED OXIDE  20% MICROETHENE HANDCOMPOUNDED C-PLASTIC 30% TO 1.00% CA  325F/3 TONS	122-1A	0.46	0.051	0.051	3.551	1.4	0.051	10.807	204.347826				204.347826	
			122-2A	0.43	0.05	0.05	3.386	5.4	0.051	41.686	1131.19015				1131.19015	
			122-3A	0.41	0.05	0.05	3.228	1.45	0.051	11.193	246.724055				246.724055	
			122-4A	0.43	0.052	0.052	3.256	0.82	0.052	6.208	90.6976744				90.6976744	
			124	124A 07-JAN-93	LAMINATES 80% LOADING DOPED OXIDE  20% MICROETHENE HANDCOMPOUNDED C-PLASTIC 1.5% TO 3.0% CA  325F/3 TONS	123-1A	0.49	0.08	0.08	2.411	0.58	0.08	2.854	18.3673469		
123-2A	0.36	0.081				0.081	1.750	0.37	0.081	1.798	2.77777778				2.77777778	
123-3A	0.58	0.08				0.08	2.854	0.74	0.081	3.597	26.0110685				26.0110685	
123-4A	0.43	0.081				0.081	2.090	0.51	0.08	2.510	20.0872093				20.0872093	
123-5A	0.44	0.078				0.078	2.221									
123-6A	0.65	0.078				0.078	3.281									
123-7A	0.62	0.076				0.076	3.212									
123-8A	0.6	0.076				0.076	3.108									
123-9A	0.66	0.078				0.078	3.331									
123-10A	0.6	0.076				0.076	3.108									
123-11A	0.9	0.08				0.08	4.429									
123-12A	0.68	0.08				0.08	3.346									
123-13A	0.6	0.072				0.072	3.281									
123-14A	0.52	0.075				0.075	2.730									
123-15A	0.54	0.075				0.075	2.835									

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
125A	125A 01/12/93	124-4A (3.0%)	0.66		0.077		3.375								
		LAMINATES													
		TEMP 230F TO 400F													
		85% DOPED OXIDE PELLETS													
		HANDCOMPOUNDED													
		C-PLASTIC													
		125-1A (300F)	0.41		0.057		2.832								
		125-2A (300F)	0.73		0.057		5.042								
		125-3A (350F)	0.42		0.05		3.307								
		125-4A (350F)	0.59		0.051		4.555								
		125-5A (375F)	0.45		0.051		3.474								
		125-6A (375F)	0.44		0.052		3.331								
		125-7A (400F)	0.39		0.051		3.011								
		125-8A (400F)	0.39		0.051		3.011								
		125-11A (275F)	0.58		0.057		4.006								
		125-12A (275F)	0.38		0.057		2.625								
126	126A 01/14/93	LAMINATES													
		80% TO 90% LOADING													
		DOPED OXIDE(7/92)													
		35% CA													
		SAMPLES 1&2													
		.30% CA													
		SAMPLES 3-7													
		HANDCOMPOUNDED													
		C-PLASTIC													
		MICROTHENE (5/92)													
		325F/3 TONS													
		126-1A (80%)	1.45		0.061		9.358								
		126-2A (80%)	2.85		0.061		18.394						1.969		25
		126-3A (85%)	0.32		0.08		1.575	0.4			0.08		1.709		22.2222222
		126-4A (85%)	0.27		0.076		1.399	0.33			0.076				
129A	01/15/93	275F/3 TONS													
		126-6A (82.5%)	1.4		0.073		7.550	1.45			0.073		7.820		3.57142857
		126-7A (82.5%)	0.52		0.062		3.302	0.53			0.062		3.366		1.92307692
		LAMINATES													
		85% DOPED OXIDE PELLETS													
		14% TO 22%													
		KET (9/92)													
		325F/3 TONS													
		129-1A (15%)	0.54		0.05		4.252								
		129-2A (15%)	0.64		0.048		5.249								
		129-3A (16%)	0.55		0.049		4.419								
		129-4A (16%)	0.56		0.049		4.499								

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
130A	130A 01/19/93	129-5A (16%)	0.75		0.05		5.906								
		129-6A (18%)	0.66		0.049		5.303								
		129-7A (22%)	0.63		0.051		4.863								
		129-8A (22%)	0.38		0.05		2.992								
		LAMINATE 325F/3 TONS													
130A	130A 01/19/93	130-1A (18%)	0.46		0.049		3.696		0.71		0.049		5.705		54.3478261
		130-2A (18%)	0.46		0.044		4.116		0.76		0.045		6.649		61.5458937
		130-3A (16%)	0.43		0.044		3.848		0.53		0.044		4.742		23.255814
		130-4A (16%)	0.49		0.043		4.486		0.64		0.044		5.727		27.6437848
131A	131A 01/27/93	LAMINATE 325F/3 TONS													
		131-1A(3 TONS)	0.58		0.061		3.743								
		131-3A(15 TONS)	0.74		0.055		5.297								
		131-4A(15 TONS)	0.51		0.052		3.861								
		131-5A(3 TONS)	0.78		0.076		4.041								
132A	132A 01/28/93	LAMINATE 325F/3 TONS													
		132-1A(3 TONS)	1.3		0.057		8.979								
		132-2A(3 TONS)	1.5		0.048		12.303								
		132-3A(15 TONS)	0.96		0.05		7.559								
		132-4A(15 TONS)	0.79		0.051		6.099								
133A	133A 01/28/93	LAMINATE 325F/3 TONS													
		133-1A(3 TONS)	0.36		0.069		2.054								
		133-2A(3 TONS)	0.32		0.065		1.938								
		133-3A(15 TONS)	0.44		0.051		3.397								
		133-4A(15 TONS)	0.5		0.052		3.786								
134A	134A 01/28/93	LAMINATE 325F/3 TONS													
		134-1A(3 TONS)	0.76		0.058		5.159		0.83		0.058		5.634		9.21052632
		134-2A(3 TONS)	0.63		0.057		4.351		0.69		0.058		4.684		7.63546798
		134-3A(15 TONS)	0.85		0.049		6.830		0.72		0.049		5.785		-15.2941176
		134-4A(15 TONS)	0.76		0.051		5.867		0.68		0.05		5.354		-8.73684211
135A	01/28/93	LAMINATE 325F/3 TONS													
		135-1A(.010")	0.65		0.029		8.824		0.61		0.03		8.005		-9.28205128
		135-2A(.010")	0.6		0.034		6.948		0.57		0.034		6.600		-5
		135-3A(.006")	0.56		0.029		7.602		0.51		0.029		6.924		-8.92857143
		135-4A(.006")	0.62		0.029		8.417		0.72		0.029		9.775		16.1290323
136A	02/01/93	LAMINATE 325F/3 TONS													
		136-1A(22%)	0.39		0.034		4.516								

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
137A	02/03/93	LAMINATE 325F/3 TONS 137-1A 137-2A 137-3A 137-4A	0.57	0.033	6.800										
			0.34	0.035	3.825										
			0.39	0.034	4.516										
MFP	02/03/93	LAMINATE 325F/3 TONS MRP-1 MRP-2 MRP-3 MRP-4	0.48	0.056	3.375	0.59	0.056	4.148	22.9166667						
			0.41	0.061	2.646	0.48	0.06	3.150	19.0243902						
			0.49	0.054	3.572	0.89	0.054	6.489	81.6326531						
			0.43	0.058	2.919	0.47	0.058	3.190	9.30232558						
138A	02/04/93	LAMINATE 325F/3 TONS 138-1A 138-2A 138-3A 138-4A	0.34	0.03	4.462										
			0.6	0.032	7.382										
			0.43	0.036	4.703										
			0.35	0.035	3.937										
139A	02/05/93	LAMINATE 325F/3 TONS 139-1A(18%) 139-2A(18%) 139-3A(22%) 139-4A(22%)	0.39	0.022	6.979										
			0.36	0.025	5.669										
			0.33	0.026	4.997										
			0.4	0.027	4.997										
BR AND R3	02/05/93	LAMINATE 325F/3 TONS BR-1 BR-2 R3-1 R3-2	0.76	0.039	7.672										
			0.85	0.039	8.581										
			0.47	0.042	4.406										
			0.51	0.049	4.098										
EXTRUDED 3/24/93		168-1A 100/115/120/125 168-2A 100/110/120/125 168-3A LAMINATION STOPPED	1.2												
			IR TOO HIGH.												
			LAMINATION STOPPED.												
169A	03/25/93	LAMINATE 325F/3 TONS 169-1A	0.89	0.041	8.5461878	>100									

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
		169-2A	0.52	0.041	4.9932783	>100									
170A	03/26/93	LAMINATE 325F/3 TONS													
		170-1A	0.68	0.041	6.5296716	0.66	0.041	6.337622431	-2.94117647						
		170-2A	0.9	0.041	8.6422124	0.86	0.041	8.258114077	-4.44444444						
171A	03/30/93	LAMINATE 325F/3 TONS													
		171-1A	0.35	0.035	3.9370079	0.74	0.035	8.323959505	111.428571						
		171-2A	0.68	0.035	7.6490439	1.05	0.036	11.48293963	50.122549						
		171-3A	0.52	0.039	5.2493438										
		171-4A	0.55	0.038	5.6983009										
173A	04/2/93	LAMINATE 325F/3 TONS													
		173-1A	0.34	0.039	3.4322633	0.36	0.04	3.543307087	3.23529412						
		173-2A	0.41	0.039	4.1389057	0.48	0.041	4.60917995	11.3622844						
175A	04/05/93	LAMINATE 325F/3 TONS													
		175-1A(160)	0.55	0.041	5.281352	0.79	0.041	7.585942001	43.6363636						
		175-2A(160)	0.39	0.042	3.655793	0.53	0.042	4.968128984	35.8974359						
		175-3A(180)	0.47	0.043	4.3032412	0.68	0.043	6.22595594	44.6808511						
		175-4A(180)	0.44	0.042	4.1244844	0.58	0.043	5.310382714	28.7526427						
176A	04/06/93	LAMINATE 325F/3 TONS													
		176-1A(160)	0.42	0.04	4.1338583	0.43	0.04	4.232283465	2.38095238						
		176-2A(160)	0.49	0.04	4.8228346	0.49	0.041	4.705204532	-2.43902439						
		176-3A(180)	0.38	0.039	3.836059	0.39	0.039	3.937007874	2.63157895						
		176-4A(180)	0.35	0.038	3.6261915	0.36	0.04	3.543307087	-2.28571429						
		176-1A	0.42	0.04	4.1338583	0.67	0.04	6.594488189	59.5238095						
		176-3A	0.38	0.039	3.836059	0.59	0.04	5.807086614	51.3815789						
		176-4A	0.35	0.038	3.6261915	0.5	0.04	4.921259843	35.7142857						



SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
177A	04/12/93	*176-3A	0.38	0.039	4.134	0.9	8.58267717	114.278368							
		*SAMPLE TESTED FOR 30 DAYS													
		176-3A	0.38	0.039	4.134	0.64	6.46073087	56.282798							
		READING TAKEN AFTER 1 DAY													
		176-3A	0.38	0.039	4.134	0.833	8.198818898	98.3265336							
177A	04/12/93	READING TAKEN AFTER 2 DAYS													
		LAMINATE 325F/3 TONS													
		177-1A(160)	0.61	0.041	5.8574995	0.53	5.089302862	-13.1147541							
		177-2A(160)	0.81	0.044	7.2476736	0.74	6.936632921	-4.29159318							
		177-3A(180)	1.05	0.043	9.6136239	0.77	7.217847769	-24.9206349							
178A	04/14/93	177-4A(180)	0.84	0.044	7.5161059	0.65	5.951290972	-20.8194906							
		LAMINATE 325F/3 TONS													
		178-1A(160)	0.54	0.046	4.6217049	0.58	4.964053406	7.40740741							
		178-2A(160)	0.64	0.047	5.361032	0.68	5.949256343	10.9722222							
		178-3A(180)	0.53	0.045	4.6369204	0.48	4.199475066	-9.43396226							
179A	04/15/93	178-4A(180)	0.45	0.041	4.3211062	0.48	4.60917995	6.66666667							
		LAMINATE 325F/3 TONS													
		179-1A(160)	0.39	0.045	3.4120735	0.46	4.024496938	17.9487179							
		179-2A(160)	0.31	0.043	2.838308	0.39	3.570774583	25.8064516							
		179-3A(180)	0.28	0.043	2.563633	0.34	3.11298297	21.4285714							
181A	04/28/93	179-4A(180)	0.31	0.043	2.838308	0.38	3.479216261	22.5806452							
		LAMINATE 325F/3 TONS													
		181-1A(200)	0.47	0.063	2.9371329	0.58	3.683007366	25.3946465							
		181-2A(200)	0.4	0.059	2.6691579	0.56	3.86793756	44.9122807							
		181-3A(180)	0.54	0.064	3.3218504	0.61	3.75246063	12.962963							

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM) BEFORE	THICKNESS (INCH) BEFORE	RESISTIVITY (OHM-CM) BEFORE	RESISTANCE (OHM) AFTER	THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
181A	04/28/93	181-4A(180)	0.55	0.064	3.3833661	0.58	0.064	3.567913386	5.45454545
182A	04/28/93	LAMINATE 325F/3 TONS							
4V BATTERIES FOR PASTE ADHESION		182-1A(200) SANDED	0.68	0.073	3.6673498				
		182-2A(200) Pb THEN SANDED	0.7	0.06	4.5931759				
		182-3A(180) SANDED	0.68	0.071	3.7706554				
		182-4A(180) Pb THEN SANDED	0.6	0.058	4.0727668				
183A	04/29/93	LAMINATE 325F/3 TONS							
		183-1A	0.38	0.043	3.4792163	0.54	0.044	4.831782391	38.8755981
		183-2A	0.38	0.043	3.4792163	0.55	0.048	4.511154856	29.6600877
		183-3A	0.38	0.059	2.5357	0.55	0.059	3.670092086	44.7368421
		183-4A	0.38	0.057	2.6246719	0.58	0.059	3.870278927	47.4576271
184A	05/04/93	LAMINATE 325F/3 TONS							
		184-1A	0.58	0.046	4.9640534	0.78	0.046	6.67579596	34.4827586
		184-2A	0.5	0.046	4.2793564	0.8	0.047	6.701289998	56.5957447
		184-3A	0.58	0.05	4.5669291	0.76	0.051	5.866913695	28.4651792
185A	05/05/93	LAMINATE 325F/3 TONS							
		185-1A	0.38	0.055	2.7201145	0.58	0.055	4.151753758	52.6315789
		185-2A THICK SUBSTRATE	0.29	0.048	2.3786089	0.41	0.05	3.228346457	35.7241379
186A	05/05/93	LAMINATE 325F/3 TONS							
		186-1A	1	0.041	9.6024582	1.55	0.042	14.52943382	51.3095238
		186-2A	0.82	0.041	7.8740157	1.3	0.043	11.90258194	51.1627907
187A		LAMINATE 330F/2 TONS							
		187-1A	0.155	0.03	2.0341207	10.5	0.03	137.7952756	6674.19355

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
188A		LAMINATE 330F/2 TONS	0.135	0.135	0.029	0.029	1.832745	1.832745	20	6.2	0.029	0.029	271.5177844	84.17051317	14714.8148
189A	06/14/93	LAMINATE 295F/3 TONS	0.14	0.14	0.028	0.031	1.9685039	1.7780036	6	9	0.03	0.03	78.74015748	118.1102362	3900
190A	06/16/93	LAMINATE 295F/3 TONS	0.47	0.54	0.051	0.045	3.6282229	4.7244094	0.7	0.83	0.051	0.045	5.403736298	7.261592301	48.9361702
191A	06/18/93	LAMINATE 295F/3 TONS	0.25	0.255	0.044	0.045	2.2369363	2.2309711	1.6	0.97	0.044	0.044	14.31639227	8.679312813	540
192A	06/18/93	LAMINATE 295F/3 TONS	0.23	0.29	0.043	0.044	2.1058414	2.5948461	0.48	0.58	0.044	0.044	4.294917681	5.189692198	103.952569
193A	06/18/93	LAMINATE 295F/3 TONS	1.3	1.9	0.051	0.049	10.03551	15.265949	3.5	4.4	0.049	0.05	28.12148481	34.64566929	180.21978
193A	06/18/93	LAMINATE 295F/3 TONS	0.19	0.26	0.062	0.058	1.2065024	1.7648656	0.82	2.2	0.062	0.059	5.207010414	14.68036834	331.578947

IR OF SAMPLE WAS TOO HIGH. NEW SAMPLES WILL BE MADE AND TESTED

READING TAKEN AFTER BEING STORED FOR 2.5 MONTHS

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
194A	06/24/93	LAMINATE 295F/3 TONS 194-1A(.008") 194-2A(.008") 194-3A(.010") 194-4A(.010")	0.265		0.031		3.3655067		8.5		0.032		104.5767717		3007.31132
			0.32		0.042		2.999625		>100		0.043				
			0.29		0.04		2.8543307		>100		0.04				
			0.31		0.034		3.5896248		4.4		0.034		509.4951366		14093.5484
195A	06/28/93	LAMINATE 295F/3 TONS 195-1A 195-2A	0.46		0.046		3.9370079		0.65		0.046		5.5631633		41.3043478
			0.58		0.046		4.9640534		0.72		0.046		6.162273194		24.137931
196A	06/28/93	LAMINATE 295F/3 TONS 196-1A 196-2A	1.15		0.044		10.289907		1.15		0.045		10.06124234		-2.22222222
			1.05		0.045		9.1863517		1.3		0.045		11.3735783		23.8095238
197A	06/29/93	LAMINATE 295F/3 TONS 197-1A(315F) 197-2A(315F) 197-3A(335F) 197-4A(335F) 197-5A(355F) 197-6A(355F) 197-7A(375F) 197-8A(375F) 197-9A(400F) 197-10A(400F)	0.24		0.044		2.1474588		0.7		0.045		6.124234471		185.185185
			0.275		0.045		2.4059493		0.65		0.045		5.686789151		136.363636
			0.225		0.045		1.9685039		0.73		0.045		6.386701662		224.444444
			0.36		0.051		2.7790644		0.81		0.051		6.252894859		125
			0.24		0.044		2.1474588		0.37		0.045		3.237095363		50.7407407
			0.22		0.045		1.9247594		0.275		0.045		2.405949256		25
			0.235		0.045		2.055993		0.29		0.045		2.537182852		23.4042553
			0.215		0.045		1.8810149		0.3		0.045		2.624671916		39.5348837
			0.205		0.045		1.7935258		0.275		0.045		2.405949256		34.1463415
			0.2		0.046		1.7117426		0.275		0.045		2.405949256		40.5555556
198A	06/29/93	LAMINATE 295F/3 TONS 198-1A(315F) 198-2A(315F) 198-3A(335F) 198-4A(335F) 198-5A(355F) 198-6A(355F) 198-7A(375F) 198-8A(375F) 198-9A(400F)	0.43		0.049		3.4549253		0.86		0.049		6.909850554		100
			0.41		0.05		3.2283465		1.25		0.05		9.842519685		204.878049
			0.295		0.047		2.4711007		0.82		0.047		6.868822248		177.966102
			0.32		0.052		2.4227741		0.54		0.052		4.088431254		68.75
			0.28		0.046		2.3964396		1.75		0.044		15.65855404		553.409091
			0.23		0.046		1.9685039		4		0.044		35.79098067		1718.18182
			0.21		0.047		1.7590886		1.95		0.046		16.6894899		848.757764
			0.36		0.049		2.8924956		0.65		0.048		5.331364829		84.3171296
			0.245		0.048		2.0095144		1.2		0.046		10.27045532		411.091393

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
199A	07/21/93	198-10A(400F)	0.24	0.045	2.097375	1.3	0.045	11.3735783	441.866667						
		STABILITY TESTING WAS SHORTENED BY ONE DAY ON SAMPLES 1-4													
		PROBLEM WITH POWER SUPPLY ON SAMPLES 5A-8A													
		LAMINATE 295F/3 TONS													
200A	07/23/93	199-1A(NOT SANDED)	0.66	0.044	5.9055118										
		199-2A(NOT SANDED)	0.62	0.043	5.676616										
		199-3A(SANDED)	0.31	0.044	2.773801	0.5	0.045	4.374453193	57.7060932						
		199-4A(SANDED)	0.37	0.043	3.3876579	0.54	0.044	4.831782391	42.6289926						
201A	07/23/93	LAMINATE 295F/3 TONS													
		201-1(325)	0.32	0.046	2.7387881	0.4	0.043	3.662332906	33.7209302						
		201-2(350)	0.295	0.043	2.7009705	0.4	0.043	3.662332906	35.5932203						
		201-3(375)	0.34	0.044	3.0422334	0.45	0.045	3.937007874	29.4117647						
202A	07/23/93	201-4(400)	0.31	0.044	2.773801	0.58	0.044	5.189692198	87.0967742						
		201-5(425)	0.31	0.044	2.773801	1.4	0.044	12.52684324	351.612903						
		LAMINATE 295F/3 TONS													
		202-1(325)	0.41	0.043	3.7538912	0.71	0.043	6.500640908	73.1707317						
203A	07/23/93	202-2(350)	0.31	0.043	2.838308	0.48	0.043	4.394799487	54.8387097						
		202-3(375)	0.35	0.044	3.1317108	0.54	0.044	4.831782391	54.2857143						
		202-4(400)	0.38	0.043	3.4792163	0.54	0.044	4.831782391	38.8755981						
		202-5(425)	0.295	0.044	2.6395848	0.98	0.044	8.768790265	232.20339						
204A	07/27/93	LAMINATE 295F/3 TONS													
		203-1(325)	0.34	0.044	3.0422334	3.1	0.042	29.05886764	855.182073						
		203-2(350)	0.42	0.044	3.758053	2.2	0.044	19.68503937	423.809524						
		203-3(375)	0.36	0.044	3.2211883	5	0.042	46.86914136	1355.02646						
204A	07/27/93	203-4(400)	0.5	0.044	4.4738726	3	0.043	27.4674968	513.953488						
		LAMINATE 300F/3 TONS													
		204-1A(250)	0.62	0.046	5.3064019	1.6	0.046	13.69394043	158.064516						
		204-2A(275)	0.45	0.044	4.0264853	0.83	0.044	7.42662849	84.4444444						
204A	07/27/93	204-3A(300)	0.51	0.045	4.4619423	0.68	0.045	5.949256343	33.3333333						
		204-4A(325)	0.51	0.045	4.4619423	0.98	0.045	8.573928259	92.1568627						
		204-5A(350)	0.47	0.044	4.2054402	2.9	0.044	25.94846099	517.021277						
		204-6A(375)	0.46	0.044	4.1159628	2.35	0.045	20.55993001	399.516908						

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
205A SEE BATTERY BUILD															
206A	8/10/93	LAMINATE 300F/3 TONS 206-1A(SP006) 206-2A(SP006)	0.275 0.25		0.053 0.052		2.0427871 1.8927922		0.34 0.31		0.053 0.053		2.525627693 2.30277819		23.6363636 21.6603774
		206-3A(SP007) 206-4A(SP007)	0.36 0.23		0.052 0.053		2.7256208 1.7085129		0.48 0.34		0.052 0.052		3.634161114 2.574197456		33.3333333 50.6688963
207A	8/10/93	LAMINATE 300F/3 TONS 207-1A(SP006) 207-2A(SP006)	0.83 0.48		0.043 0.041		7.5993408 4.60918		1.65 0.64		0.042 0.042		15.46681665 5.99250094		103.528399 30.1587302
		207-3A(SP007) 207-4A(SP007)	0.96 0.89		0.043 0.042		8.789599 8.3427072		1 0.86		0.044 0.041		8.947745168 8.258114077		1.79924242 -1.01397643
208A	8/11/93	LAMINATE 300F/3 TONS 208-1A 208-2A 208-3A 208-4A	0.4 0.5 0.3 0.32		0.037 0.038 0.036 0.038		4.2562247 5.1802735 3.2808399 3.3153751		0.6 0.7 0.54 0.73		0.039 0.038 0.037 0.039		6.056935191 7.252382926 5.745903384 7.369271149		42.3076923 40 75.1351351 122.275641
209A	8/16/93	LAMINATE 300F/3 TONS 209-1A(SANDED) 209-2A	0.96 1.35		0.051 0.053		7.4108384 10.028228		3.4 4.3		0.051 0.053		26.24671916 31.941762		254.166667 218.518519
210A RIBBON FROM DE WAL	8/24/93	LAMINATE 300F/3 TONS 210-1A 210-2A 210-3A 210-4A	0.28 0.23 0.41 0.56		0.033 0.033 0.041 0.042		3.3404915 2.7439752 3.9370079 5.2493438		13.75 11 2.4 2.4		0.033 0.034 0.043 0.043		164.0419948 127.3737842 21.97399744 219.7399744		4810.71429 4541.94373 458.139535 4086.04651
211A	9/2/93	LAMINATE 300F/3 TONS													

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
212A	9/8/93	LAMINATE 300F/3 TONS	0.56	0.032	6.8897638	0.69	0.03	9.05511811	31.4285714						
			0.41	0.031	5.2070104	0.62	0.031	7.874015748	51.2195122						
			0.32	0.024	5.2493438	0.56	0.024	9.186351706	75						
			0.33	0.023	5.6487504	0.8	0.024	13.12335958	132.323232						
213A	9/16/93	LAMINATE 350F/3 TONS	0.86	0.044	7.6950608	1.25	0.044	11.18468146	45.3488372						
			0.99	0.044	8.8582677	4.4	0.044	39.37007874	344.444444						
			0.64	0.043	5.8597326	2.3	0.043	21.05841421	259.375						
			0.72	0.043	6.5921992	1.9	0.043	17.3960813	163.888889						
214A	9/20/93	LAMINATE 350F/3 TONS	2.6	0.035	29.246344										
			3.4	0.036	37.182852										
			3.8	0.035	42.744657										
			2.8	0.036	30.621172										
			2.5	0.04	24.606299										
215A	9/22/93	LAMINATE 350F/3 TONS	3	0.036	32.808399										
			0.5	0.067	2.9380656										
			0.6	0.082	2.8807375										
			0.84	0.081	4.082823										
			0.82	0.081	3.9856129										
216A	9/27/93	LAMINATE 350F/30 TONS	0.86	0.081	4.1800331										
216A	9/27/93	LAMINATE 350F/30 TONS	0.45	0.022	8.0529707	8.3	0.022	148.5325698	1744.4444						
			0.3	0.021	5.624297	6.9	0.022	123.4788833	2095.45455						
			0.34	0.022	6.084667	9.5	0.022	170.0071582	2694.11765						
			0.36	0.022	6.4423765	16	0.022	286.3278454	4344.4444						
216A	9/27/93	LAMINATE 350F/30 TONS	0.37	0.024	6.0695538	3.7	0.024	60.69553806	900						
			0.285	0.022	5.1002147	1.7	0.021	31.87101612	524.895572						
			0.34	0.021	6.3742032	0.92	0.021	17.24784402	170.588235						
			0.37	0.02	7.2834646	1.9	0.02	37.4015748	413.513514						

\*SAMPLES NOT SURFACE TREATED

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
217A	9/29/93	LAMINATE 300F/3 TONS													
		217-1A	0.48	0.052	0.052	0.052	3.6341611	0.66	0.66	0.052	0.052	0.052	4.996971532	37.5	
		217-2A	0.43	0.05	0.05	0.05	3.3858268	0.5	0.5	0.05	0.05	0.05	3.937007874	16.2790698	
		217-3A	0.47	0.052	0.052	0.052	3.5584494	0.51	0.51	0.052	0.052	0.052	3.861296184	8.5106383	
		217-4A	0.46	0.05	0.05	0.05	3.6220472	0.6	0.6	0.05	0.05	0.05	4.724409449	30.4347826	
218A	9/29/93	LAMINATE 300F/3 TONS													
		218-1A	0.9	0.051	0.051	0.051	6.947661								
		218-2A	1	0.051	0.051	0.051	7.7196233								
		218-3A	0.7	0.051	0.051	0.051	5.4037363								
		218-4A	0.73	0.051	0.051	0.051	5.635325								
219A	10/4/93	LAMINATE 350F/3 TONS													
		219-1A(30 TONS)	0.46	0.038	0.038	0.038	4.7658516	0.73	0.73	0.038	0.038	0.038	7.563199337	58.6956522	
		219-2A(30 TONS)	0.4	0.038	0.038	0.038	4.1442188	0.74	0.74	0.038	0.038	0.038	7.666804807	85	
		219-3A(30 TONS)	0.37	0.039	0.039	0.039	3.73511	0.8	0.8	0.04	0.04	0.04	7.874015748	110.810811	
		219-4A(30 TONS)	0.43	0.04	0.04	0.04	4.2322835	0.77	0.77	0.04	0.04	0.04	7.578740157	79.0697674	
220A	10/6/93	LAMINATE 300F/3 TONS													
		220-1A	0.34	0.021	0.021	0.021	6.3742032	0.88	0.88	0.022	0.022	0.022	15.7480315	147.058824	
		220-2A	0.3	0.019	0.019	0.019	6.2163282	0.69	0.69	0.019	0.019	0.019	14.29755491	130	
		220-3A	0.28	0.02	0.02	0.02	5.511811	0.54	0.54	0.02	0.02	0.02	10.62992126	92.8571429	
		220-4A	0.34	0.019	0.019	0.019	7.045172	0.7	0.7	0.019	0.019	0.019	14.50476585	105.882353	
221A	10/11/93	LAMINATE 300F/3 TONS													
		221-1A	0.83	0.045	0.045	0.045	7.2615923	1.15	1.15	0.045	0.045	0.045	10.06124234	38.5542169	
		221-2A	0.81	0.044	0.044	0.044	7.2476736	1.1	1.1	0.044	0.044	0.044	9.842519585	35.8024691	
		221-3A	0.85	0.045	0.045	0.045	7.4365704	1	1	0.045	0.045	0.045	8.748906387	17.6470588	
		221-4A	0.92	0.044	0.044	0.044	8.2319256	1.3	1.3	0.044	0.044	0.044	11.63206872	41.3043478	
222A	10/15/93	LAMINATE 300F/3 TONS													
		222-1A	0.8	0.026	0.026	0.026	12.11387	1.15	1.15	0.026	0.026	0.026	17.41368867	43.75	
		222-2A	1.2	0.025	0.025	0.025	18.897638	1.1	1.1	0.025	0.025	0.025	17.32283465	-8.33333333	
		222-3A	0.78	0.025	0.025	0.025	12.283465	1.15	1.15	0.025	0.025	0.025	18.11023622	47.4358974	
		222-4A	0.91	0.025	0.025	0.025	14.330709	0.82	0.82	0.025	0.025	0.025	12.91338583	-9.89010989	
223A	10/18/93	LAMINATE 300F/3 TONS													
		223-1A	0.54	0.044	0.044	0.044	4.8317824	0.55	0.55	0.045	0.045	0.045	4.811898513	-0.41152263	
		223-2A	0.49	0.044	0.044	0.044	4.3843951	0.7	0.7	0.044	0.044	0.044	6.263421618	42.8571429	
		223-3A(WI)	.470/.620	0.044	0.044	0.044	5.54	1.15	1.15	0.045	0.045	0.045	10.06124234	81.6108726	
		223-4A(WI)	.440/.450	0.045	0.045	0.045	3.93	1	1	0.044	0.044	0.044	8.947745168	127.677994	
224A	10/19/93	FIRST WITHOUT SOW, SECOND WITH LAMINATE 350F/3 TONS													
		224-1A	1.7	0.08	0.08	0.08	8.3661417								



SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
225A	10/20/93	LAMINATE 300F/3 TONS (TTS)225-1A (TTS)225-2A (138S)225-3A (138S)225-4A	1.65		0.08		8.1200787							
226A	10/21/93	LAMINATE 300F/3 TONS (TTS)226-1A (TTS)226-2A (138S)226-3A (138S)226-4A (30 DAYS)226-3A	0.175		0.046		1.4977747		0.36		0.045		3.149606299	110.285714
			0.195		0.045		1.7060367		0.46		0.044		4.115962777	141.258741
			0.235		0.046		2.0112975		0.285		0.045		2.49343832	23.9716312
			0.21		0.045		1.8372703		0.245		0.046		2.096884629	14.1304348
227A	10/22/93	LAMINATE 300F/3 TONS 227-1A 227-2A 227-3A 227-4A	0.14		0.028		1.9685039		100		0.028		1406.074241	71328.5714
			0.16		0.028		2.2497188		100		0.028		1406.074241	62400
			0.23		0.028		3.2339708		0.23		0.028		3.233970754	0
			0.28		0.027		4.082823		0.34		0.029		4.615802335	13.0541872
			0.23		0.028		3.2339708		0.28		0.028		3.937007874	21.7391304
228A	10/25/93	LAMINATE 300F/3 TONS 228-1A(TTS) 228-1A(TTS) 228-3A(138S) 228-4A(138S)	0.84		0.044		7.5161059		0.9		0.044		8.052970651	7.14285714
			0.96		0.043		8.789599		1.15		0.043		10.5292071	19.7916667
			0.94		0.044		8.4108805		1.1		0.044		9.842519685	17.0212766
			0.94		0.043		8.6064823		1		0.045		8.748906387	1.65484634
229A	10/26/93	LAMINATE 300F/3 TONS 229-1A(TTS) 229-1A(TTS) 229-3A(138S) 229-4A(138S)	0.35		0.046		2.9955495		0.73		0.046		6.247860322	108.571429
			0.3		0.045		2.6246719		0.67		0.045		5.861767279	123.333333
			0.47		0.045		4.111986		0.62		0.045		5.42432196	31.9148936
			0.44		0.045		3.8495188		0.54		0.045		4.724409449	22.7272727
229A	10/26/93	LAMINATE 300F/3 TONS 229-1A(TTS) 229-1A(TTS) 229-3A(138S) 229-4A(138S)	0.47		0.045		4.111986		0.68		0.044		6.084466714	47.9690522
			0.57		0.045		4.9868766		0.74		0.045		6.474190726	29.8245614
			0.74		0.044		6.6213314		0.92		0.044		8.231925555	24.3243243
			0.6		0.044		5.3686471		0.75		0.044		6.710808876	25

\*SAMPLES SURFACE TREATED

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
230A	10/29/93	LAMINATE 300F/3 TONS													
		230-1A(TTS)	0.29	0.044	0.044	0.044	2.5948461	0.68	0.68	0.044	0.044	6.084466714	134.482759		
		230-1A(TTS)	0.31	0.043	0.043	0.043	2.838308	0.59	0.59	0.044	0.044	5.279169649	85.9970674		
		230-3A(138S)	0.45	0.043	0.043	0.043	4.1201245	0.52	0.52	0.044	0.044	4.652827487	12.9292929		
		230-4A(138S)	0.34	0.044	0.044	0.044	3.0422334	0.42	0.42	0.044	0.044	3.758052971	23.5294118		
138S															
231A	10/29/93	LAMINATE 300F/3 TONS													
		231-1A(TTS)	0.41	0.044	0.044	0.044	3.6685755	1.3	1.3	0.044	0.044	11.63206872	217.073171		
		231-1A(TTS)	0.32	0.044	0.044	0.044	2.8632785	2.2	2.2	0.045	0.045	19.24759405	572.222222		
		231-3A(138S)	0.49	0.044	0.044	0.044	4.3843951	0.68	0.68	0.044	0.044	6.084466714	38.7755102		
		231-4A(138S)	0.52	0.044	0.044	0.044	4.6528275	0.65	0.65	0.044	0.044	5.816034359	25		
232A	10/29/93	LAMINATE 300F/3 TONS													
		232-1A(TTS)	0.34	0.044	0.044	0.044	3.0422334								
		232-1A(TTS)	0.36	0.044	0.044	0.044	3.2211883								
		232-3A(138S)	0.57	0.044	0.044	0.044	5.1002147	0.71	0.71	0.044	0.044	6.352899069	24.5614035		
		232-4A(138S)	0.58	0.044	0.044	0.044	5.1896922	0.62	0.62	0.044	0.044	5.547602004	6.89655172		
233A	10/29/93	LAMINATE 300F/3 TONS													
		233-1A(TTS)	0.22	0.045	0.045	0.045	1.9247594								
		233-1A(TTS)	0.23	0.044	0.044	0.044	2.0579814								
		233-3A(138S)	0.28	0.044	0.044	0.044	2.5053686	2.25	2.25	0.044	0.044	20.13242663	703.571429		
		233-4A(138S)	0.35	0.045	0.045	0.045	3.0621172	1.2	1.2	0.044	0.044	10.7372942	250.649351		
234A	11/7/93	LAMINATE 300F/3 TONS													
		234-1A(TTS)	0.45	0.044	0.044	0.044	4.0264853								
		234-1A(TTS)	0.46	0.044	0.044	0.044	4.1159628								
		234-3A(138S)	0.5	0.044	0.044	0.044	4.4738726	1.05	1.05	0.044	0.044	9.395132427	110		
		234-4A(138S)	0.64	0.044	0.044	0.044	5.7265569	1.35	1.35	0.043	0.043	12.36037356	115.843023		
235A	11/7/93	LAMINATE 300F/3 TONS													
		235-1A(TTS)	0.46	0.044	0.044	0.044	4.1159628								
		235-1A(TTS)	0.44	0.044	0.044	0.044	3.9370079								
		235-3A(138S)	0.76	0.044	0.044	0.044	6.8002863	0.66	0.66	0.044	0.044	5.905511811	-13.1578947		
		235-4A(138S)	0.68	0.044	0.044	0.044	6.0844667	0.7	0.7	0.044	0.044	6.263421618	2.94117647		
236A	11/7/93	LAMINATE 300F/3 TONS													
		236-1A(TTS)	0.68	0.033	0.033	0.033	8.1126223								

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
237A	11/7/93	LAMINATE 300F/3 TONS 237-1A(TTS) 237-1A(TTS) 237-3A(138S) 237-4A(138S)	0.8		0.031		10.16002		1.3		0.043		11.90258194		23.8095238
			1.05		0.043		9.6136239		1.2		0.044		10.7372942		20.5741627
			0.95		0.042		8.9051369								
									0.96		0.044		8.589835361		40.027137
238A	11/7/93	LAMINATE 300F/3 TONS 238-1A 238-2A 238-3A 238-4A	0.67		0.043		6.1344076								
			0.8		0.044		7.1581961								
			0.67		0.043		6.1344076		0.96		0.044		10.7372942		144.897959
			0.49		0.044		4.3843951		1.2		0.044				
239A	11/10/93	LAMINATE 300F/3 TONS 239-1A 239-2A 239-3A 239-4A	0.42		0.044		3.758053		0.55		0.044		4.921259843		30.952381
			0.38		0.045		3.3245844		0.4		0.045		3.499562555		5.26315789
			0.36		0.044		3.2211883		0.48		0.044		4.294917681		33.3333333
			0.34		0.045		2.9746282		0.5		0.045		4.374453193		47.0586235
239A	11/10/93	LAMINATE 300F/3 TONS 239-1A 239-2A 239-3A 239-4A	0.459		0.045		4.015748		0.64		0.045		5.599300087		39.4335512
			0.39		0.045		3.4120735		0.45		0.045		3.937007874		15.3846154
			0.45		0.045		3.9370079		0.79		0.045		6.911636045		75.5555556
			0.44		0.044		3.9370079		0.58		0.044		5.189692198		31.8181818
240A	11/16/93	LAMINATE 300F/3 TONS 240-1A 240-2A 240-3A 240-4A	0.54		0.045		4.7244094		0.64		0.045		5.599300087		18.5185185
			0.66		0.044		5.9055118								
			0.6		0.045		5.2493438		0.84		0.044		7.516105941		43.1818182
			0.77		0.044		6.8897638								
241A	11/15/93	LAMINATE 300F/3 TONS 241-1A 241-2A 241-3A	0.72		0.077		3.681358		FOR BATTERY BUILD						
			0.78		0.077		3.9881378								
			0.79		0.076		4.0924161								
242A	11/18/93	LAMINATE 300F/3 TONS 242-1A 242-2A 242-3A 242-4A(NO PB)	0.59		0.066		3.5194464		FOR BATTERY BUILD						
			0.64		0.066		3.8177046								
			0.67		0.067		3.9370079								
			0.72		0.066		4.2949177								
243A	11/18/93	LAMINATE 300F/3 TONS 243-1A	0.38		0.066		2.2667621								

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
244A	11/18/93	LAMINATE 300F/3 TONS 244-1A 244-2A 244-3A 244-4A(NO PB)	0.42	2.4679751	0.067	FOR BATTERY BUILD									
			0.41	2.445717	0.066										
			0.41	2.4092138	0.067										
245A	12/11/93	LAMINATE 300F/3 TONS 245-1A 245-2A 245-3A 245-4A	0.56	3.3404915	0.066	FOR BATTERY BUILD									
			0.49	2.9229301	0.066	ACTIVE SIDE WITH NEG PASTE									
			0.5	2.9825817	0.066										
			0.49	2.9229301	0.066										
246A	12/13/93	LAMINATE 300F/3 TONS 246-1A 246-2A 246-3A 246-4A	0.59	5.6654504	0.041				0.62		0.041		5.953524102		5.08474576
			0.55	5.1556055	0.042				0.71		0.041		6.817745343		32.2394678
			0.66	6.3376224	0.041				0.77		0.041		7.393892837		16.6666667
			0.7	6.7217208	0.041				1		0.04		9.842519685		46.4285714
247A	12/13/93	LAMINATE 300F/3 TONS 247-1A 247-2A 247-3A 247-4A	0.6	12.432656	0.019	SAMPLE BROKE									
			0.42	9.1863517	0.018				0.5		0.018		10.93613298		19.047619
			0.54	11.189391	0.019				0.52		0.019		10.77496892		-3.7037037
			0.42	8.7028595	0.019				0.52		0.019		10.77496892		23.8095238
248A	12/27/93	LAMINATE 300F/3 TONS 248-1A 248-2A 248-3A 248-4A	0.285	5.6102362	0.02				0.39		0.02		7.677165354		36.8421053
			0.34	6.6929134	0.02				0.38		0.021		7.124109486		6.44257703
			0.36	7.0866142	0.02				0.52		0.02		10.23622047		44.444444
			0.31	6.1023622	0.02				0.45		0.02		8.858267717		45.1612903
249A	1/5/94	LAMINATE 300F/3 TONS 249-1A 249-2A 249-3A 249-4A	0.52	10.774969	0.019				1		0.019		20.72109407		92.3076923
			0.4	8.7489064	0.018				0.66		0.018		14.43569554		65
			0.48	9.4488189	0.02				1		0.02		19.68503937		108.333333
			0.46	10.061242	0.018				0.66		0.019		13.67592209		35.9267735
250A	1/5/94	LAMINATE 300F/3 TONS 250-1A 250-2A	0.88	17.322835	0.02				0.8		0.02		15.7480315		-9.09090909
			0.38	7.8740157	0.019				0.34		0.019		7.045171985		-10.5263158
			0.38	7.8740157	0.019				0.42		0.019		8.702859511		10.5263158
			0.4	7.8740157	0.02				0.44		0.02		8.661417323		10
*SAMPLE NOT SANDED PRIOR TO LAMINATION															
250A	1/5/94	LAMINATE 300F/3 TONS 250-1A 250-2A	0.88	8.4501632	0.041				0.84		0.041		8.066064913		-4.54545455
			0.5	4.8012291	0.041				0.46		0.041		4.417130785		-8

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM) BEFORE	THICKNESS (INCH) BEFORE	RESISTIVITY (OHM-CM) BEFORE	RESISTANCE (OHM) AFTER	THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
251A	1/5/94	LAMINATE 300F/3 TONS 251-1A 251-2A	0.19 0.225	0.041 0.041	1.8244671 2.1605531	0.24 0.23	0.041 0.041	2.304589975 2.208565393	26.3157895 2.2222222
252A	1/7/94	LAMINATE 300F/3 TONS 252-1A 252-2A	0.15 0.125	0.041 0.042	1.4403687 1.1717285	0.195 0.18	0.041 0.042	1.872479355 1.687289089	30 44
253A	1/7/94	LAMINATE 300F/3 TONS 253-1A 253-2A(30 TONS)	0.15 0.155	0.019 0.011	3.1081641 5.547602	0.245 0.11	0.02 0.01	4.822834646 4.330708661	55.1666667 -21.9354839
254A	1/12/94	LAMINATE 300F/3 TONS 254-1A 254-2A 254-3A 254-4A	0.38 0.4 0.46 0.5	0.021 0.021 0.02 0.021	7.1241095 7.4930626 9.0551181 9.3738283	0.32 0.48 0.64 0.6	0.021 0.021 0.02 0.021	5.999250094 8.998875141 12.5984252 11.24859393	-15.7894737 20 39.1304348 20
255A	1/20/94	LAMINATE 300F 3 TONS/30 TONS 255-1A(3 TONS) 255-2A(3 TONS) 255-3A(30 TONS) 255-4A(30 TONS)	0.3 0.29 0.28 0.235	0.016 0.019 0.011 0.011	7.3818898 6.0091173 10.021475 8.4108805	0.265 0.28 0.32 0.295	0.016 0.019 0.011 0.011	6.520669291 5.801906341 11.45311382 10.5583393	-11.6666667 -3.44827586 14.2857143 25.5319149
256A	1/20/94	LAMINATE 300F/3 TONS NO SHIM 256-1A 256-2A 256-3A 256-4A	0.44 0.62 0.41 0.45	0.018 0.019 0.019 0.019	9.623797 12.847078 8.4956486 9.3244923	0.79 1.3 0.78 0.9	0.018 0.019 0.019 0.019	17.27909011 26.9374223 16.16245338 18.64898467	79.5454545 109.677419 90.2439024 100
257A	1/24/94	LAMINATE 300F/3 TONS .045".031" SHIM 257-1A 257-2A 257-3A 257-4A 257-5A	0.76 0.74 0.8 0.9 0.77	0.04 0.04 0.04 0.041 0.04	7.480315 7.2834646 7.8740157 8.6422124 7.5787402	1AKE BATTERY #257 (12V) FULL PB SHEET			

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)	
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
STABILITY TESTING																
258A	1/25/94	257-6A	0.73	0.028	10.264342	0.91	0.028	12.79527559	24.6575342							
		257-7A	0.79	0.028	11.107987	1.2	0.029	16.29106706	46.6608468							
		LAMINATE 300F/3 TONS														
		.045" .031" SHIM														
		258-1A	0.36	0.041	3.456885	FOR BATTERY #258 4V										
259A	1/26/94	258-2A	0.4	0.042	3.7495313	CRACKED DURING ASSEMBLY										
		258-3A	0.34	0.034	3.9370079	FOR BATTERY #258 4V										
		STABILITY TESTING														
		258-4A	0.295	0.029	4.0048873	0.36	0.029	4.887320119	22.0338983							
		258-5A	0.33	0.029	4.4800434	0.4	0.029	5.430355688	21.2121212							
LAMINATE 300F/3 TONS																
260A	2/4/94	.045" .031" SHIM														
		259-1A	0.71	0.041	6.8177453											
		259-2A	0.78	0.043	7.1415492											
		259-3A	0.6	0.041	5.7614749	N UPON PRESSING IN THE PB SHEET										
		259-4A	0.69	0.04	6.7913386											
		259-5A	0.7	0.042	6.5616798											
		259-6A	0.7	0.029	9.5031225											
		STABILITY TESTING														
		259-7A	0.51	0.026	7.7225924	0.48	0.026	7.268322229	-5.88235294							
		259-8A	0.51	0.027	7.4365704	0.54	0.027	7.874015748	5.88235294							
LAMINATE 300F/3 TONS																
261A	2/4/94	.045" .031" SHIM														
		260-1A	0.56	0.041	5.3773766	DOUG-										
		260-2A	0.49	0.042	4.5931759	TO MAKE 4V BATTERY										
		260-3A	0.35	0.03	4.5931759	AMINATE BROKE										
		STABILITY TESTING														
		260-4A	0.46	0.028	6.4679415	0.54	0.027	7.874015748	21.7391304							
		260-5A	0.34	0.026	5.1483949	0.49	0.026	7.419745609	44.1176471							
		LAMINATE 300F/3 TONS														
		.045" .031" SHIM														
		261-1A	0.41	0.042	3.8432696	ULD NOT STICK TO LAMINATE										
262A	2/4/94	261-2A	0.42	0.042	3.9370079	"	"	"	"							
		261-3A	0.42	0.03	5.511811	"	"	"	"							
		STABILITY TESTING														
		261-4A	0.43	0.026	6.5112053	0.38	0.026	5.754088431	-11.627907							
		261-5A	0.44	0.026	6.6626287	0.46	0.025	7.244094488	8.72727273							
		LAMINATE 375F/3 TONS														
		NO SHIM														
		262-1A	0.52	0.017	12.042612	0.74	0.016	18.20866142	51.2019231							
		262-2A	0.6	0.017	13.895322	0.72	0.016	17.71653543	27.5							
		262-3A	0.53	0.017	12.274201	0.69	0.016	16.97834646	38.3254717							
262-4A	0.51	0.017	11.811024	0.63	0.016	15.5019685	31.25									

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
263A	2/1/94	LAMINATE 300F/3 TONS 0.045" SHIM 263-1A 263-2A	0.5 0.49	" "	0.043 0.043	" "	4.5779161 4.4863578	" "	ATTY #263 6V-FULL PB SHEET				
264A	2/4/94	LAMINATE 300F/3 TONS 0.031" SHIM 264-1A 264-2A	0.46 0.41		0.034 0.034		5.3265401 4.7475683		MAKE BATTERY #264 4V 3STRATE CRACKED				
265A	2/4/94	LAMINATE 300F/3 TONS 0.031" SHIM 265-1A 265-2A 265-3A 265-4A 265-5A	0.3 0.28 0.33 0.33 0.33		0.033 0.033 0.032 0.032 0.032		3.5790981 3.3404915 4.0600394 4.0600394 4.0600394		MAKE BATTERY #265-6V " " DELAMINATED AT CORNER MAKE BATTERY #265-4V MINATE CRACKED				
266A	2/18/94	LAMINATE 300F/3 TONS 0.051" SHIM 266-1A 266-2A 266-3A 266-4A	0.36 0.38 0.41 0.4		0.046 0.045 0.046 0.045		3.0811366 3.3245844 3.5090722 3.4995626		0.37 0.48 0.84 0.46	0.045 0.044 0.045 0.045	3.237095363 4.294917681 7.349081365 4.024496938	5.0617284 29.1866029 109.430894 15	
267A	3-3-94	LAMINATE 300F/3 TONS 267-1A(C) 267-2A(P) 267-3A(P) 267-4A(P) 267-5A(P) 267-6A(P) 267-7A(P) 267-8A(C) 267-9A(C) 267-10A(C) 267-11A(C) 267-12A 267-13A	0.52 0.61 0.63 0.45 0.43		0.039 0.037 0.038 0.036 0.036		5.2493438 6.4907427 6.5271446 4.9212598 4.7025372		0.73 0.6 0.55 0.56 0.56	0.044 0.041 0.041 0.041 0.039	6.531853973 5.761474938 5.281352026 5.377376608 5.653139511	W/ PB SHEET " " " " MINATED, PB SHEET	
							5.31496063 4.921259843 3.937007874 3.641732283 5.089302862 5.377376608 4.681847202 5.030621172		0.04 0.04 0.04 0.04 0.041 0.041 0.037 0.036	" " " " " " -4.86486486 6.97674419			
268A	3-3-94	LAMINATE 300F/3 TONS 268-1A	0.45 0.43		0.036 0.036		4.9212598 4.7025372		0.44 0.46	0.037 0.036	4.681847202 5.030621172	-4.86486486 6.97674419	W/ PB SHEET

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
269A	3/3/94	LAMINATE 300F/3 TONS	0.6		0.045	0.046	5.2493438	0.65			0.046	5.5631633			"
			0.53		0.044	0.046	4.7423049	0.58			0.046	4.964053406			"
			0.49		0.044	0.046	4.3843951	0.57			0.046	4.878466279			"
			0.54		0.04	0.047	5.3149606	0.62			0.047	5.193499749			"
						0.048	4.019028871	0.49			0.048	4.019028871			INATED, PB SHI
						0.048	3.772965879	0.46			0.048	3.772965879			"
						0.049	4.017354973	0.5			0.049	4.017354973			"
						0.048	3.772965879	0.46			0.048	3.772965879			"
						0.045	8.223972003	0.94			0.045	8.223972003			"
			0.52		0.043	0.044	4.7610328	0.54			0.044	4.831782391			1.48601399
			0.48		0.043	0.044	4.3947995	0.56			0.044	5.010737294			14.0151515
270A	3/4/94	LAMINATE 300F/3 TONS	0.6		0.025	0.027	9.4488189	0.81			0.027	11.81102362			25
			0.44		0.028	0.028	6.1867267	0.6			0.028	8.436445444			36.3636364
			0.55		0.028	0.028	7.7334083	0.68			0.028	9.561304837			23.6363636
			0.36		0.021	0.021	6.7491564	0.6			0.021	11.24859393			66.6666667
271A	3/10/94	LAMINATE 300F/3 TONS	0.94		0.018	0.018	20.56993	0.35			0.018	7.655293088			-62.7659574
			0.824		0.022	0.022	14.745884	0.98			0.022	17.53758053			18.9320388
			0.745		0.02	0.02	14.665354	PLASTIC CRACKED							
			0.4		0.018	0.018	8.7489064	0.44			0.018	9.623797025			10
			0.59		0.022	0.021	10.558339	0.74			0.021	13.87326584			31.3962873
272A	3/17/94	LAMINATE 300F/3 TONS	0.37		0.02	0.02	7.2834646	0.39			0.02	7.677165354			5.40540541
			0.34		0.02	0.02	6.6929134	0.31			0.02	6.102362205			-8.82352941
			0.245		0.019	0.02	5.076668	0.43			0.02	8.464566929			66.7346939
			0.345		0.02	0.022	6.7913386	0.35			0.022	6.263421618			-7.77338603
273A	3/17/94	LAMINATE 300F/3 TONS	0.3		0.028	0.027	4.2182227	0.58			0.027	8.457276174			100.493827
			0.33		0.028	0.028	4.640045	0.65			0.028	9.139482565			96.969697
			0.36		0.028	0.028	5.0618673	0.43			0.028	6.046119235			19.4444444
			0.36		0.028	0.028	5.0618673	0.41			0.028	5.764904387			13.8888889
274A	4/28/94	LAMINATE 300F/3 TONS	0.38		0.04	0.041	3.7401575	0.94			0.041	9.026310736			141.335045
			0.34		0.04	0.04	3.3464567	0.72			0.04	7.086614173			111.764706
			0.39		0.041	0.041	3.7449587	0.65			0.041	6.241597849			66.6666667
			0.37		0.042	0.041	3.4683165	0.52			0.041	4.993278279			43.9883586
274A	4/28/94	LAMINATE 300F/3 TONS	2.8		0.052	0.054	21.199273	9			0.054	65.6167979			209.52381
			3		0.058	0.059	20.363834	10			0.059	66.72894702			227.883616



SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
275A	4/28/94	LAMINATE 300F/3 TONS 275-1A 275-2A	2.65		0.044		23.711525		24.5		0.044		219.2197566		824.528302
			1.95		0.042		18.278965		50		0.044		447.3872584		2347.55245
276A	4/28/94	LAMINATE 300F/3 TONS 276-1A 276-2A	3.2		0.06		20.997375		6.8		0.064		41.83070866		99.21875
			3.8		0.06		24.934383		5		0.062		31.7500635		27.3344652
277A	5/2/94	LAMINATE 300F/3 TONS 277-1A 277-2A 277-3A 277-4A	0.58		0.047		4.8584352		DR 4V BATTERY		277-1 C				
			NA		0.041		NA		DR 4V BATTERY		277-2 C				
			NA		0.042		NA		DR 6V BATTERY		277-6V C				
			NA		0.042		NA		"		"				
278A	5/2/94	LAMINATE 300F/3 TONS 278-1A 278-2A 278-3A	NA		0.04		NA		DR 4V BATTERY		278-1 C				
			NA		0.039		NA		DR 6V BATTERY		278-6V C				
			NA		0.04		NA		"		"				
279A	5/2/94	LAMINATE 300F/3 TONS 279-1A 279-2A 279-3A 279-4A	NA		0.042		NA		DR 4V BATTERY		279-1 C				
			NA		0.039		NA		DR 4V BATTERY		279-2 C				
			NA		0.04		NA		DR 6V BATTERY		279-6V C				
			NA		0.039		NA		"		"				
280A	5/9/94	LAMINATE 300F/3 TONS 280-1A 280-2A 280-3A 280-4A	0.38		0.035		4.2744657		2.75		0.037		29.26154501		584.566145
			0.31		0.039		3.1294165		8.1		0.04		79.72440945		2447.58065
			0.28		0.035		3.1496063		3		0.037		31.92168546		913.513514
			0.3		0.035		3.3745782		2.3		0.037		24.47329219		625.225225
281A	5/12/94	LAMINATE 300F/3 TONS 281-1A 281-2A	0.43		0.033		5.1300406		DR 4V BATTERY		281-1 C				
			0.41		0.035		4.6119235		DR 4V BATTERY		281-2 C				

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
282A	5/13/94	281-3A	0.3		0.034		3.4738305		R 6V BATTERY		281-6V C				
		281-4A	0.36		0.034		4.1685966		"		"				
		LAMINATE 300F/3 TONS													
		282-1A	0.4		0.035		4.4994376		R 4V BATTERY		282-1 C				
283A	5/13/94	282-2A	0.42		0.037		4.469036		R 4V BATTERY		282-2 C				
		282-3A	0.38		0.036		4.1557305		R 6V BATTERY		282-6V C				
		282-4A	0.4		0.036		4.3744532		"		"				
		LAMINATE 300F/3 TONS													
284A	5/25/94	283-1A	0.52		0.025		8.1889764		2.85		0.025		44.88188976		448.076923
		283-2A	0.5		0.025		7.8740157		2.35		0.025		37.00787402		370
		283-3A	0.45		0.025		7.0866142		3.3		0.025		51.96850394		633.333333
		283-4A	0.36		0.024		5.9055118		2.5		0.024		41.01049869		594.444444
285A	6/2/94	LAMINATE 300F/3 TONS													
		284-1A	0.5		0.041		4.8012291		1.1		0.041		10.56270405		120
		284-2A	0.54		0.041		5.1853274		1.4		0.041		13.44344152		159.259259
		284-3A	0.55		0.041		5.281352		1.6		0.041		15.36393317		190.909091
286A	6/2/94	284-4A	0.7		0.04		6.8897638		1.6		0.041		15.36393317		122.996516
		LAMINATE 300F/3 TONS													
		285-1A	0.89		0.045		7.7865267		OR 4V BATTERY		285-1				
		285-2A	1.15		0.046		9.8425197								
287A	6/3/94	285-3A	1.25		0.048		10.252625								
		285-4A	1.35		0.047		11.308427								
		LAMINATE 300F/3 TONS													
		286-1A	1.1		0.047		9.2142737		DONT USE						
288A	6/15/94	286-2A	1.25		0.049		10.043387		OR 4V BATTERY		286-2				
		286-3A	1.05		0.05		8.2677165								
		286-4A	1.25		0.051		9.6495291		DONT USE						
		LAMINATE 300F/3 TONS													
288A	6/15/94	287-1A	0.9		0.047		7.5389512		DONT USE						
		287-2A	0.6		0.043		5.4934994		OR 4V BATTERY		287-2				
		287-3A	0.595		0.044		5.3239084		OR 4V BATTERY		287-3				
		287-4A	0.53		0.043		4.8525911								
288A	6/15/94	LAMINATE 300F/3 TONS													
		288-1A	0.66		0.041		6.3376224		E, SUBSTRATE CRACKED						

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)	
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
289A	6/16/94	288-2A	0.8		0.042		7.4990626		OR 4V BATTERY 288-2		
		288-3A	0.54		0.041		5.1853274				
		288-4A	0.92		0.042		8.623922				
		LAMINATE 300F/3 TONS									
		289-1A	0.56		0.04		5.511811		OR 4V BATTERY 289-1		
		289-2A	0.52		0.04		5.1181102				
		289-3A	0.53		0.041		5.0893029				
290A	6/23/94	289-4A	0.55		0.04		5.4133858				
		LAMINATE 300F/3 TONS									
		290-1A	0.68		0.018		14.873141		OR 4V BATTERY 290-1		
		290-2A	0.7		0.019		14.504766		OR 4V BATTERY 290-6V		
		290-3A	0.62		0.019		12.847078		"		
		290-4A	0.66		0.02		12.992126		"		
		290-5A	0.52		0.02		10.23622		"		
		290-6A	0.49		0.02		9.6456693		"		
		290-7A	0.44		0.019		9.1172814		"		
		290-8A	0.5		0.019		10.360547		"		
		290-9A	0.5		0.021		9.3738283		"		
		290-10A	0.5		0.021		9.3738283		"		
		290-11A	0.52		0.021		9.7487814		"		
		290-12A	0.54		0.021		10.123735		"		

## APPENDIX B

### DELIVERABLE DATA

**BUILD ID**

WPG-6

**Description**

12 V Bipolar Battery

**ASSEMBLY**

Substrate Type 5.9375" X 9.1875" X 0.012" tin-lead alloy sheet

Grid Type 0.016" thick metallic screen soldered to the substrate

Separator Type, Dimensions 5.125" X 8.562" X 0.029"

Positive Paste Density 3.35 g/cc

Negative Paste Density 3.75 g/cc

Plate ID	PTE D2	D5		D7		D8		D9		D10		NTE D4
Pb Mass (g.)	260.90	158.80		160.20		162.60		158.10		161.60		261.90
AM Mass (g.)	51.70	104.30		104.20		106.00		103.50		104.80		53.40
Dry AM (g.)	51.70	52.19	52.11	52.52	51.68	52.92	53.08	52.26	51.24	51.94	52.86	53.40
Sep. Mass (g.)	Cell 1	3.54	Cell 2	3.52	Cell 3	3.53	Cell 4	3.53	Cell 5	3.52	Cell 6	3.51

Termination Copper stud soldered to terminal electrode

Containment Type Solvent bonded ABS. Container core thickness = 0.668"

Completed Mass 3.5121 kg

**FORMATION**

Acid Gravity Chilled 1.265

% Sodium Sulfate 1.5

Method of Fill Vacuum

Time 27H:55M:04S

Amps 1.0

Voltage Limit 16.32

Amp Hours 20.62

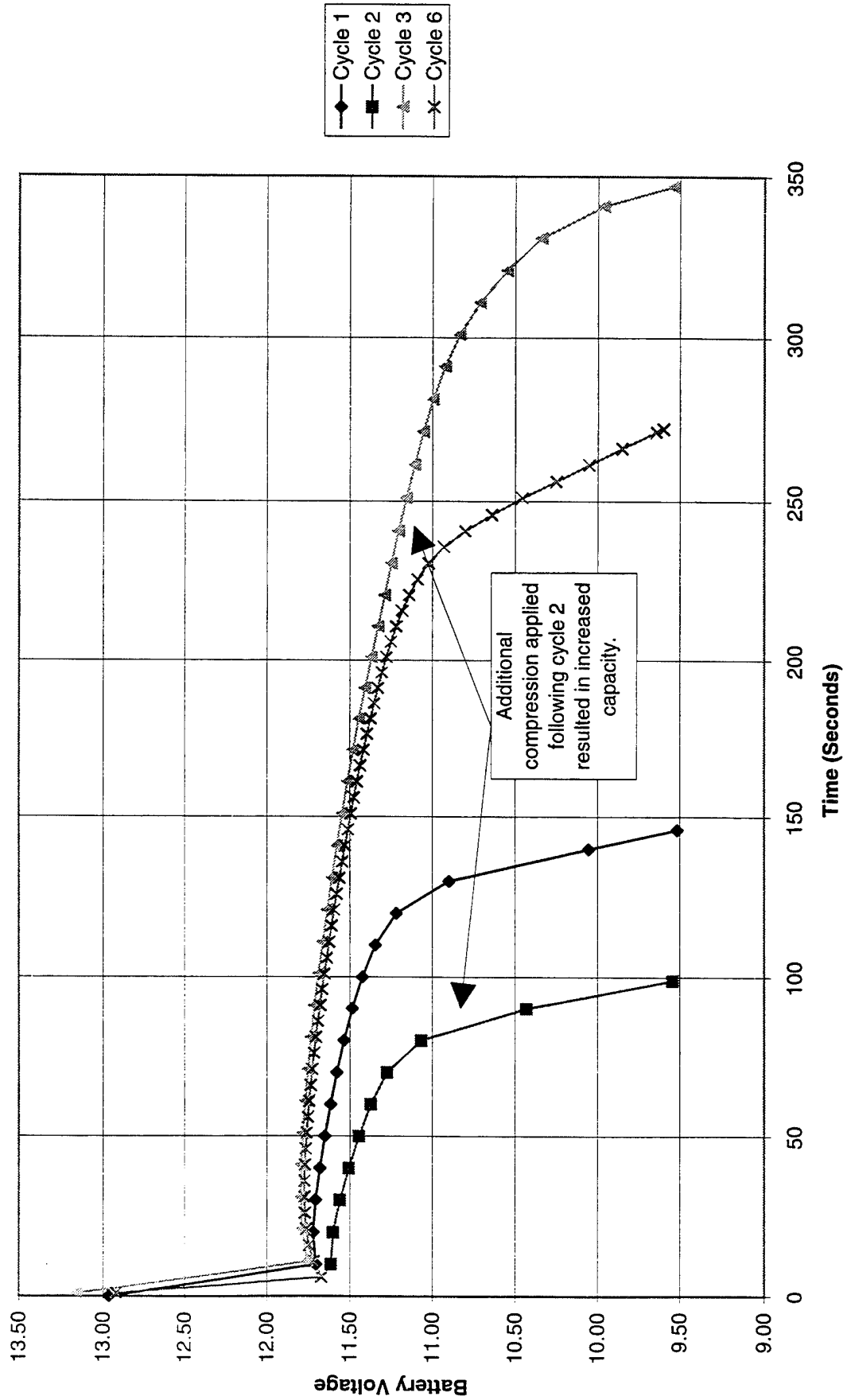
Watt Hours 311.8

Internal Resistance 13.5 mΩ

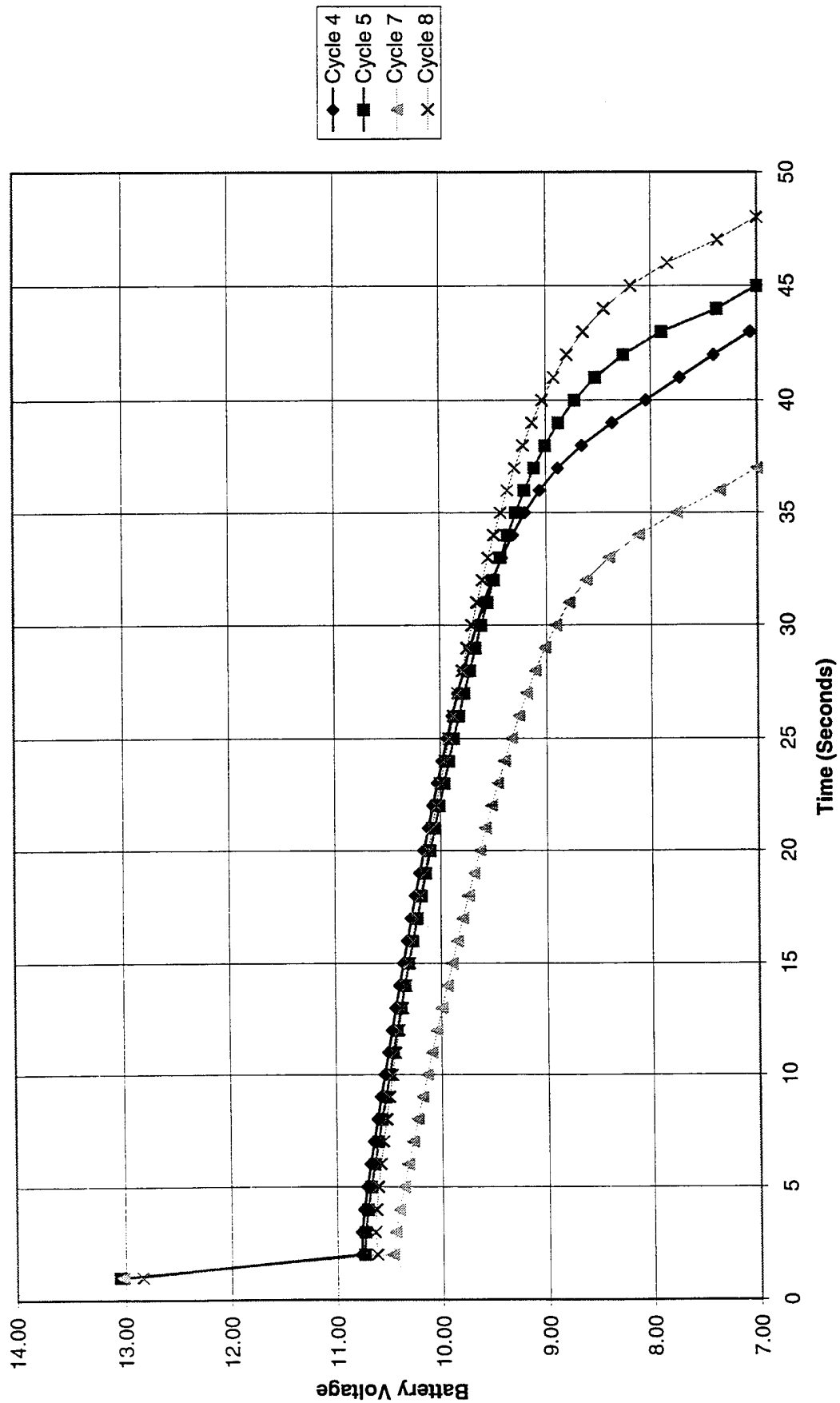
**CYCLING HISTORY**

Cycle	Date	IR (mΩ)	OCV	Discharge				Recharge				
				Amps	EODV	Ah	Wh	Amps	Vlimit	Ah	Wh	% Rchg
1	11/15/95	13.5	12.966	21	9.6	0.85	9.6	0.5	15.30	0.935	12.92	110
2	11/16/95	16.5	NA	21	9.6	0.57	6.4	0.1	14.40	NA	NA	NA
3	11/20/95	10.5	13.158	21	9.6	2.01	22.8	0.5	14.40	2.211	29.48	110
4	11/21/95	8.2	13.019	124	7.2	1.44	14.1	0.5	14.40	1.584	21.22	110
5	11/22/95	8.6	13.05	124	7.2	1.51	14.7	0.5	14.40	1.661	22.24	110
6	11/30/95	10.0	12.922	21	9.6	1.58	17.9	0.5	14.40	1.738	23.20	110
7	12/1/95	9.8	13.017	124	7.2	1.23	11.7	0.5	14.40	1.353	18.12	110
8	12/11/95	8.8	12.84	124	7.2	1.61	15.6	0.5	14.40	1.771	23.42	110

# WPG-6 21 Amp Discharge Curves



WPG-6  
124 Amp Discharge Curves



**BUILD ID**

WPG-8

**Description**

24 V Bipolar Battery

**ASSEMBLY**

Substrate Type 5.9375" X 9.1875" X 0.012" tin-lead alloy sheet

Grid Type 0.016" thick metallic screen soldered to the substrate

Separator Type, Dimensions 5.125" X 8.562" X 0.029"

Positive Paste Density 3.51 g/cc

Negative Paste Density 3.83 g/cc

Plate ID	PTE D54	D14		D15		D17		D18		D20		D21	
Pb Mass	258.70	162.90		162.20		161.90		162.80		163.10		162.00	
AM Mass	52.10	106.00		105.30		104.70		104.80		105.40		103.60	
Dry AM	52.10	52.71	53.29	52.41	52.89	52.65	52.05	52.33	52.47	52.37	53.03	51.85	51.75
Sep. Mass	Cell 1	3.52	Cell 2	3.53	Cell 3	3.48	Cell 4	3.52	Cell 5	3.48	Cell 6	3.47	Cell 7

Plate ID	D22		D23		D25		D26		D27		NTE D57
Pb Mass	160.40		163.10		160.90		161.90		162.80		258.50
AM Mass	103.20		102.00		106.00		101.70		103.30		54.00
Dry AM	52.05	51.15	51.24	50.76	51.22	54.78	50.75	50.95	51.51	51.79	54.00
Sep. Mass	3.49	Cell 8	3.46	Cell 9	3.49	Cell 10	3.50	Cell 11	3.51	Cell 12	3.50

Termination Copper stud soldered to terminal electrodes

Containment Type Solvent bonded ABS. Container core thickness = 1.153".

Containment Mass 5.5360 kg

**FORMATION**

Acid Gravity Chilled 1.265

% Sodium Sulfate 1.5

Method of Fill Vacuum

Time 20H:37M:03S

Amps 1.0

Voltage Limit 32.64

Amp Hours 20.62

Watt Hours 594.0

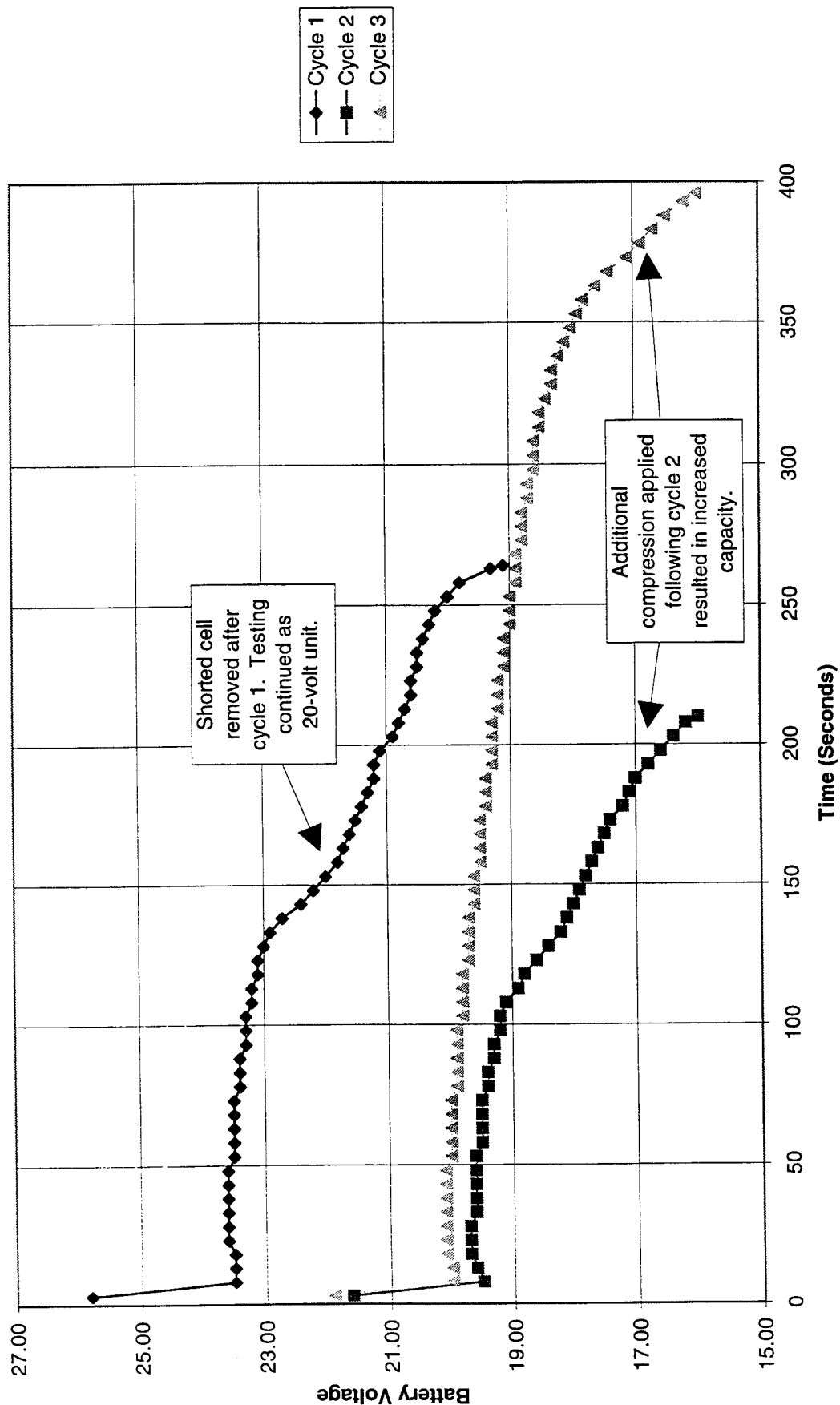
Internal Resistance 14.0 mΩ

**CYCLING HISTORY**

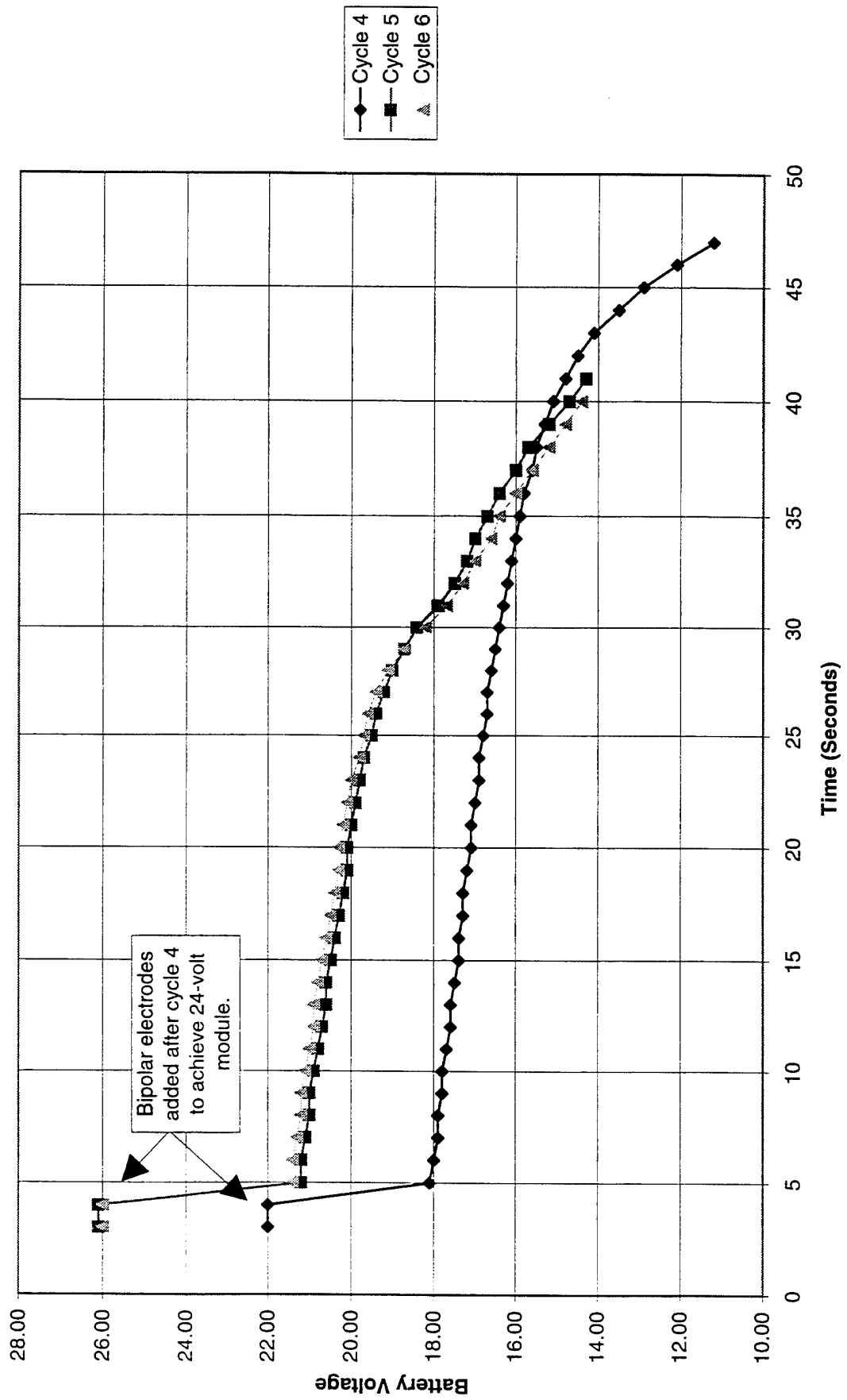
Cycle	Date	IR (mV)	OCV	Discharge				Recharge				
				Amps	EODV	Ah	Wh	Amps	Vlimit	Ah	Wh	% Rchg
1	1/16/96	14.5	25.80	21	19.2	1.50	31	0.5	30.60	1.65	44	110
1/16/96 Two shorted bipolar electrodes removed. Continue cycling as 20-volt nominal battery.												
2	1/18/96	17.5	21.60	21	16.0	1.20	20	1.0	25.50	1.32	29	110
3	1/18/96	12.5	21.90	21	16.0	2.29	41	0.1	25.50	2.51	50	110
4	1/19/96	12.5	22.00	124	12.0	1.48	23	0.1	25.50	1.62	32	110
1/23/96 Two good bipolar electrodes added to stack to achieve 24-volt module.												
5	1/24/96	17.0	26.10	124	14.4	1.27	23	0.1	30.60	1.39	28	110
6	1/26/96	16.0	26.00	124	14.4	1.24	23	0.1	30.60	1.36	27	110



# WPG-8 21 Amp Discharge Curves



# WPG-8 124 Amp Discharge Curves



**BUILD ID**

WPG-11

**Description**

12 V Bipolar Battery

**ASSEMBLY**

Substrate Type 5.9375" X 9.1875" X 0.012" tin-lead alloy sheet

Grid Type 0.016" thick metallic screen soldered to the substrate

Separator Type, Dimensions 5.125" X 8.562" X 0.029"

Positive Paste Density 3.40 g/cc

Negative Paste Density 3.75 g/cc

Plate ID	PTE D72	D66		D67		D69		D64		D65		NTE D74
Pb Mass (g.)	261.03	160.07		160.71		163.42		163.13		164.39		258.98
AM Mass (g.)	50.97	102.23		102.49		102.98		101.27		101.91		54.32
Dry AM (g.)	50.97	51.03	51.20	50.97	51.52	51.23	51.75	50.40	50.87	50.57	51.34	54.32
Sep. Mass (g.)	Cell 1	3.53	Cell 2	3.45	Cell 3	3.48	Cell 4	3.52	Cell 5	3.50	Cell 6	3.48

Termination Copper stud soldered to terminal electrode

Containment Type Solvent bonded ABS. Container core thickness = 0.671".

Containment Mass 3.4908 kg

**FORMATION**

Acid Gravity Chilled 1.265

% Sodium Sulfate 1.5

Method of Fill Vacuum

**Time**

Amps 1

Voltage Limit 16.32

Amp Hours 20.62

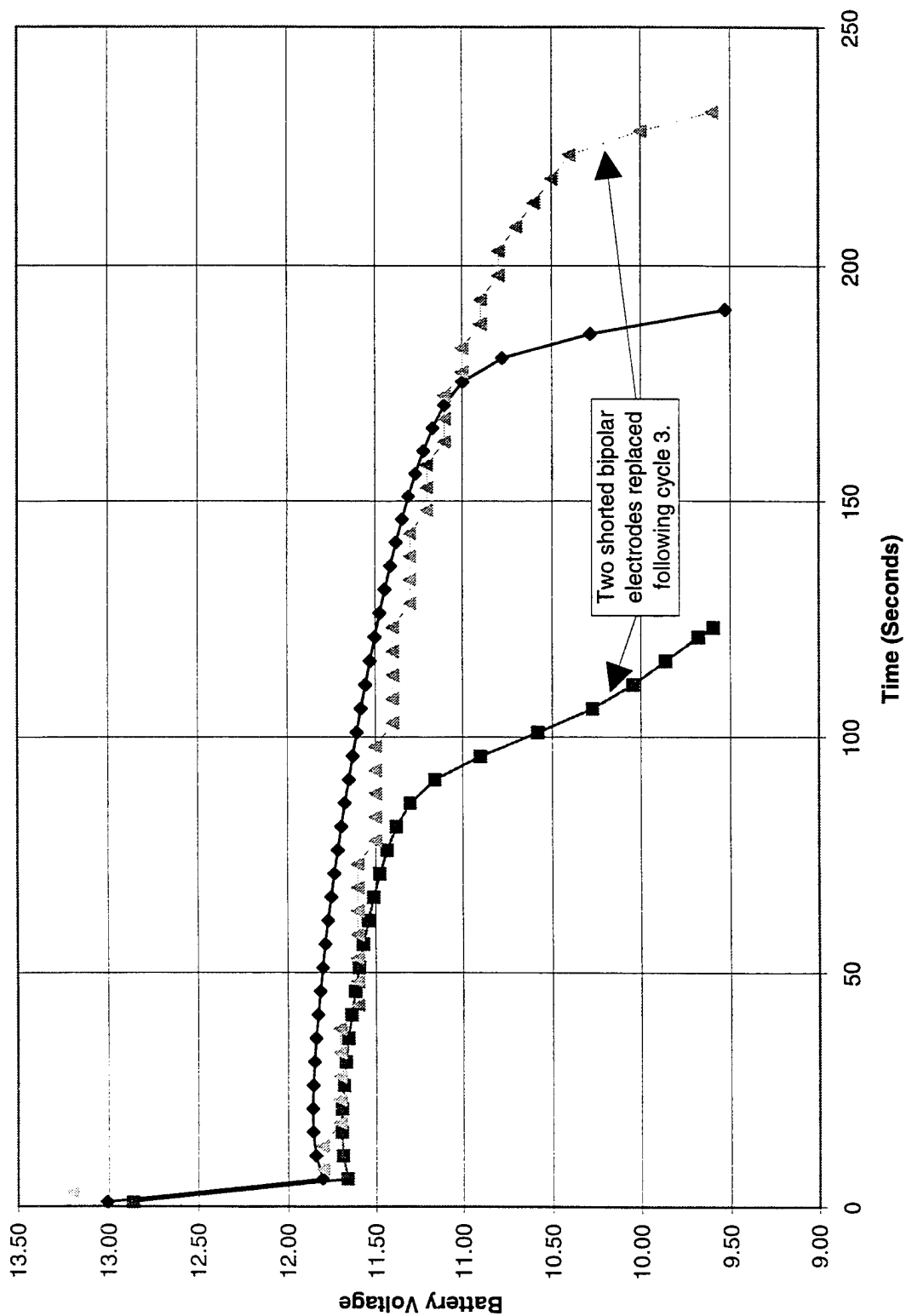
Watt Hours NA

Internal Resistance 12 mΩ

**CYCLING HISTORY**

Cycle	Date	IR (mΩ)	OCV	Discharge				Recharge				
				Amps	EODV	Ah	Wh	Amps	Vlimit	Ah	Wh	% Rchg
1	2/16/96	10.5	13.009	21	9.6	1.1	12.7	0.5	15.30	1.21	16.4	110
2	2/16/96	11.0	13.137	124	7.2	0.72	6.6	0.5	15.30	0.79	10.8	110
3	2/19/96	12.0	12.866	21	9.6	0.71	7.9	0.5	15.30	0.78	10.5	110
2/26/96 Replaced two shorted bipolar electrodes.												
4	2/27/96	11.5	13.200	21	9.6	1.33	12.0	0.5	14.40	1.46	17.0	110
5	2/28/96	11.0	13.005	124	7.2	0.82	7.0	0.5	14.40	0.90	10.0	110

# WPG-11 21 Amp Discharge Curves



WPG-11  
124 Amp Discharge Curves

